COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

"On-Line Inspection System and Testing Method for Pouch Integrity"

Short Term Project (STP)#7

FINAL TECHNICAL REPORT
Results and Accomplishments (January 1992 through March 1993)
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The off-line, destructive, inspection techniques currently used in packaged food manufacturing are not capable of rapidly detecting many package defects that occur in typical packaged food processing. Of particular concern is the detection of Meal, Ready-To-Eat (MRE) pouch integrity problems, specifically leaks and weak seals. The feasibility of three different types of units was demonstrated: a light sensor unit capable of detecting pinholes in the foil-laminate package stock, a pressure unit which detects channel leaks and tests seal strength, and a vacuum unit to detect gross leaks and seal strength. To test the pressure concept, a two-pouch bench-top unit was built by Container Integrity Corporation and then employed to detect channel leaks in the seal area of MRE pouches. The test unit detected 4-mil diameter channel leaks within 1.5 seconds 100% of the time. The technique is promising for inspection of MRE pouches, plastic cups, plastic tray-packs, and half steam-table trays. It is recommended that a working prototype production machine be built in order to determine and define the system integration and detailed component design requirements.

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Contents

1.0. Results and Accomplishments

1.1 Introduction and Background

The inspection techniques currently in use in packaged food manufacturing are not capable of rapidly detecting many package defects that occur in the typical packaged food manufacturing process. Of particular concern is the continued reliance on off-line methods to detect pouch integrity problems, specifically leaks and weak seals, rather than investing in more advanced detection systems, with less reliance on human inspectors. The currently used off-line methods, such as the dye penetrate test and the burst test are destructive, slow, and costly. Presently there is no commercially available non-destructive, on-line machine for inspecting the integrity of Meal, Ready-to-Eat (MRE) pouches. The objective of this Short Term Project (STP) is to define the feasibility of developing an on-line, non-destructive, high speed, and cost effective leak detection system for MRE pouches.

1.2 Results and Conclusions

A light sensor unit was developed which is capable of detecting 10 μm pinholes within a second in the lid stock and bottom stock. Its speed and sensitivity are sufficiently fast and accurate for on-line inspection purpose. Because pinholes are sometimes not considered to be a problem for foil laminated films, the use of the light sensor unit is an option. However, since the stretch-forming of the new horizontal-form-fill-seal operation causes some film to break or form cracks, checking for pinholes becomes a desirable or necessary step. The selection and monitoring of laminated film is essential.

The pressure unit is capable of detecting channel leaks and testing seal strength. The speed and sensitivity of this unit depends on the size of channel leaks, pressure, design of the

unit, etc. The unit can detect 1-mil diameter channel leaks within 1.5 seconds 70% of the time, and it can detect 4-mil diameter channel leaks within 1.5 seconds 100% of the time. The speed and sensitivity, as well as the consistency, could be improved using the knowledge learnt in this STP. The technique is promising for on-line inspection of MRE pouches, plastic cups, plastic tray-packs, and half steam-table trays.

The vacuum unit is capable of detecting gross leaks and testing seal strengths of MRE pouches *after retorting*.

Since there is no similar machine available commercially, significant effort would be required to design and build a working prototype, but the results of this STP show that it is feasible.

1.3 Recommendations

It is recommended that a working prototype production machine be built to perform on-line, nondestructive inspection for channel leaks and weak seals for MRE pouches, based on the concept of applying external pressure to the seal area of pouch. This project may consist of the following specific tasks: (1) determine and define the system integration requirements and the component design requirements for the prototype machine, (2) manufacture the prototype production machine, and (3) test and debug the prototype machine.

Based on the knowledge learned from this STP, the following are specific recommendations for improving the pressure unit (see Figure 2).

1. The clamping device should clamp both sides of the open channel:

   a. The outside should be a tight clamp to avoid escape of gas pressure.

b. The inside should be a loose clamp. Its function is to maintain the stability of the pouch, so that any sudden force created during initial pressurization in the open channel does not cause the pouch to move and trigger a fault signal to the proximity sensor. The clamp needs to be somewhat loose so that compressed gas can enter easily into the pouch if there is a channel leak in the seal.

2. The bottom of the pouch must be constrained with a support. When gas enters the pouch through a leak, the force caused by the gas flow can be distributed over the entire pouch. By constraining the bottom of the pouch with the support, the movement is distributed more on the lid, which can be detected by the proximity sensor.

3. Because the MRE pouch has a rather large surface area, the use of two proximity sensors is recommended. Larger pouches, such as the institutional size pouch, may require additional sensors.

The polymer melt in the seal needs time to cool before a strong bond is formed. It may be necessary at higher production rates to accelerate the formation of the seal before testing it with the pressure unit. A known way of accomplishing this is to strike the seals with cold bars immediately after applying heat.

2.0 Program Management

There were two overlapping phases in this STP with an original duration of 12 months but later extended to 15 months. The project officially began on January 1, 1992 but preliminary work started in the previous semester and it ended on March 31, 1993. The

specific tasks accomplished in this STP are listed in Figure 1.

Detailed objectives, statement of work, and CRAMTD personnel responsibilities are described in the Technical and Cost Proposals for STP #7.

2.1 Summary of Progress

- In the summer of 1991, a high school teacher intern was hired through an NSF Teacher Improvement Program to conduct a preliminary survey on the current technology for package inspection.

- Phase I was begun on January 1, 1992. During this phase, the system characteristics and requirements were established, the current technology was reviewed, and several design concepts were developed

- Three test units (a light sensor unit, a pressure unit, and a vacuum unit) were proposed to the management team at a meeting held on June 10, 1992. The concepts were approved for development and testing.

- Phase II was begun on July 1, 1992. The light sensor unit and the vacuum unit were built by Rutgers, and the pressure unit was built by Container Integrity Corporation.

- The performance of these three units was demonstrated at the Annual Contract Briefing Meeting, January 26, 1993. The light sensor unit was able to detect 10 μm pinholes within a second, the pressure unit was able to detect 1-mil channel leaks in the seal area within 1.5 seconds, and the vacuum unit was able to detect gross leaks of 80 μm or larger.

- Phase II was completed on March 31, 1993.

3.0 Short Term Project Activities

3.1 Technology Review (Phase I)

Appendix 4.1 gives a review of leak detection principles and systems. Appendix 4.2 consists of a paper entitled "Assessing Package Integrity" along with the presentation slides that were presented at the "Global Aspects of Packaging Conference", Orlando, FL, February 24-26, 1993. The presentation slides are self explanatory and provide a good background of leak detection principles and techniques. In short, there is no commercially available on-line, non-destructive inspection system for MRE pouches. The pressure differential technique is the most common technique for leak detection.

3.2 System Characteristics and Requirements (Phase I)

The system characteristics and requirements are described in Section II of Appendix 4.1. An important consideration is to determine the "minimum leak size" needed to be detected. A leak may be a pinhole in the pouch body or a micro-channel in the seal area. The size of a pinhole is easy to determine, and it is relatively easy to detect pinholes of as small as 10 µm. On the other hand, the size of a micro-channel is difficulty to determine, because micro-channels are not necessarily straight and have a uniform diameter. The possible causes for micro-channel leaks are wrinkles, voids, contamination of the seal due to poor heat sealing. Because of their higher resistance to flow compared to pinholes, micro-channels of less than 30 µm are difficult to detect, especially when the time allowed for detection is only a few seconds. Fortunately, micro-channel leaks are fairly large. Since naturally occurred micro-channels smaller than 30 µm have not been observed and are not likely to exist, there may not be a need to detect micro-channel leaks of excessively small size.

Because weak seals accounts for most of seal defects, an effective on-line inspection

system should be able to detect leaks and to test seal strength simultaneously.

3.3 Design Concept Development (Phase I)

Two design concepts were developed to inspect MRE pouches. The first design concept is useful for inspecting MRE pouches before retorting. It involves using a light sensor to detect pinholes and cracks in the lid stock and bottom web, and using a pressure differential technique to detect micro-channel leaks and to test for seal strengths of pouches. The second design concept involves using a vacuum technique to detect gross leaks and to test for seal strengths of pouches after retorting.

3.4 Decision Milestone (Phase I)

The design concepts were presented to the CRAMTD management team at a meeting on June 10, 1992. The proposed design concepts were approved for development of a bench top testing machine. The slides presented at that meeting are in Appendix 4.3.

3.5 Light Sensor Unit (Phase II)

A light sensor unit (Figure 3) was built to check for pinholes in empty formed pouches and lid stock. The unit is connected to a data acquisition system and is able to detect 10 μm pinholes within a second. Its sensitivity and response time are demonstrated to be adequate for on-line application for MRE pouches. It is a relatively inexpensive device because only a simple data acquisition system and inexpensive light sensors are required for its operation.

3.6 Pressure Test Unit (Phase II)

The basic concepts of the pressure test are illustrated and explained in Figure 4. The

relationship between the gas pressure and the plate separation is given in Appendix 4.4, and specifically Equation (3) is used as a design equation for nondestructive on-line seal strength test. In short, the gas pressure and constraining plates separation are two design variables that can be used to manipulate an appropriate test level, which is not too high to cause damage to the pouch but sufficiently high to test the strength of the seal. The on-line application of the pressure test is illustrated in Figure 5.

To test the concept, a two-pouch pressure unit (Figure 6) was built with the cooperation of Container Integrity Corporation to detect channel leaks in the seal area of MRE pouches. This unit is connected to a data acquisition system. With this test unit, external pressure is applied around the seal area of two contiguous pouches, and movement (or deflection) of the pouches due to channel leaks in the seal area is monitored by the proximity sensors. In practice, it is necessary to set a threshold deflection value above which a pouch is considered leaky. Threshold deflection values that range from 0.5 to 2.0 mil are appropriate.

Experiments were conducted using both empty and filled pouches to test the unit. Leaky pouches were made by inserting a very thin wire in the seal area, heat sealing the pouch, and then pulling the wire out after the seal was cooled. Table 1 summarizes some of the experimental results. The testing conditions (leak size, channel pressure, empty or filled pouch), threshold deflection setting, and time to reach the threshold deflection are reported. For example, the first set of experiments in Table 1 was conducted with empty MRE pouches each having a channel leak of 8 mil, the average channel pressure was 8 psi, the threshold deflected was 2 mil, and it took an average of 0.6 seconds for the test unit to detect the leak.

In short, the test unit can detect 1-mil diameter channel leaks within 1.5 seconds about 70% of the time, and it can detect 4-mil diameter channel leak within 1.5 second 100% of the time. The speed and consistency of the pressure unit could be improved with the recommendations described in Section 1.4.

3.7 Vacuum test unit (Phase II)

A vacuum test unit was built to detect gross leaks and to test the seal strength of MRE pouches. The unit consists of two parallel plates placed in a closed chamber (Figure 7) During testing, a pouch is placed between the two plates, and air is withdrawn from the chamber to create a vacuum. The pouch will expand and exert force on the parallel plates. The response is the exerted force as a function of time that is monitored with a sensitive load cell connected to a data acquisition system. The design variables are the plate separation and speed of vacuum applied. Other variables affecting the response are amount of residual gas in the pouch and leak size. Since this technique relies on expansion of gas, a minimum of 2 to 3 cc residual gas are required; this requirement is easily satisfied because all MRE pouches have residual gas of at least 3 cc.

The unit is able to detect gross leaks, such as punctures with a very fine needle. Typical experimental results from the vacuum test unit are presented in Figures 8 through 10. These figures show that the behavior of the load versus time curves for leaky pouches are significantly different from those of non-leaky pouches, and the slopes can be used as a convenient indication of leak. The amount of pressure applied to the seal for nondestructive testing can manipulated by the separation distance of the plates as described in Appendix 4.4.

This unit has potential for on-line application. However there is no similar machine available commercially, and developing an on-line unit may require considerable design efforts.

4.0 Appendix

4.1 A review of leak detection principles and systems (TWP 60).

4.2 Assessing Package Integrity. A paper presented at "Global Aspects of Packaging Conference" at Orlando, February 24-26, 1993

4.3 Materials presented at the management meeting on June 10, 1992

4.4 "Relationship between Seal Stress and Burst Pressure for Retortable Pouches" Journal of Packaging Technology and Science, Vol. 6, No. 5, Pgs 239-244, (1993).

Fig.1 - CRAMTD Short Term Project #7
On-Line Inspection for Pouch Integrity
Projected Time Events and Milestones

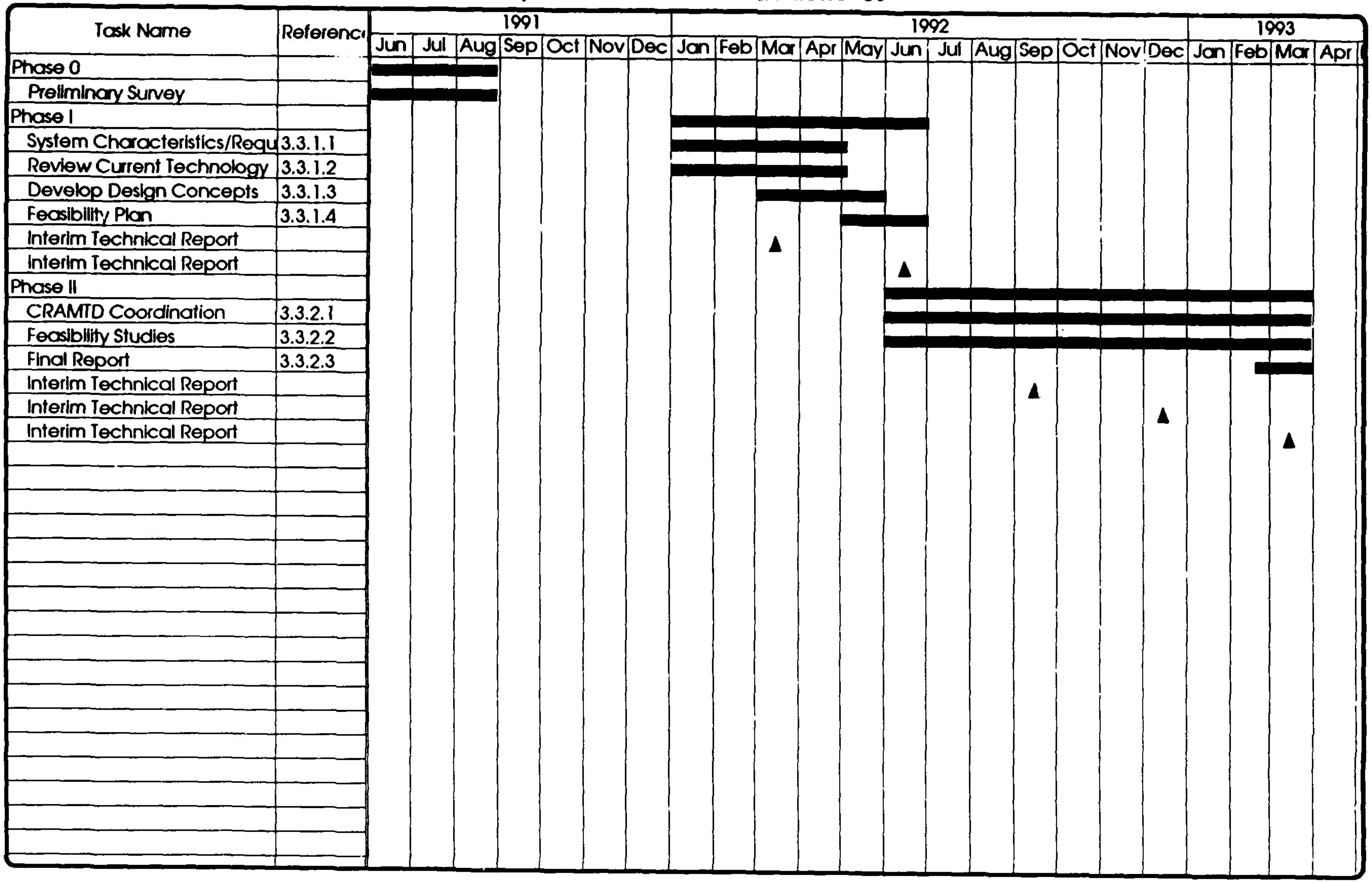

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Figure 2. Design for the Pressure Unit

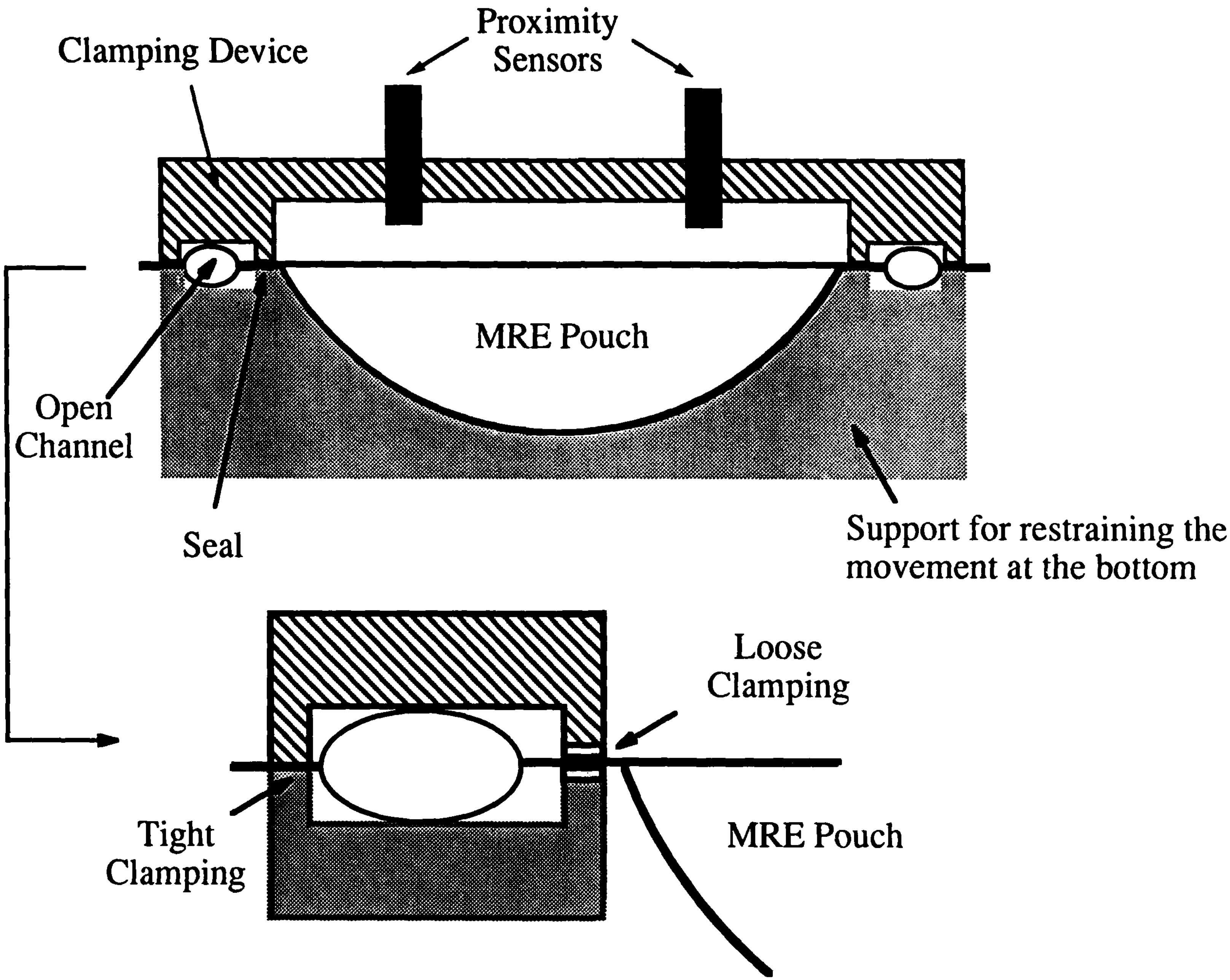
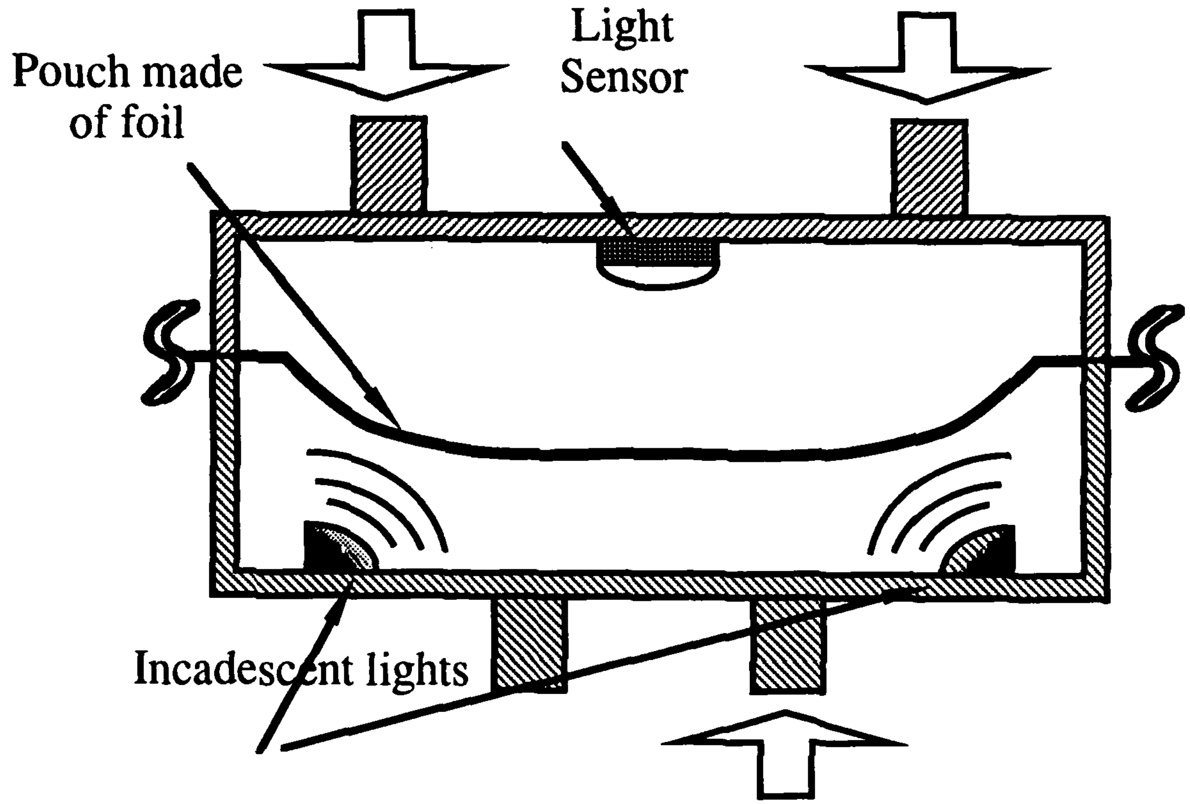
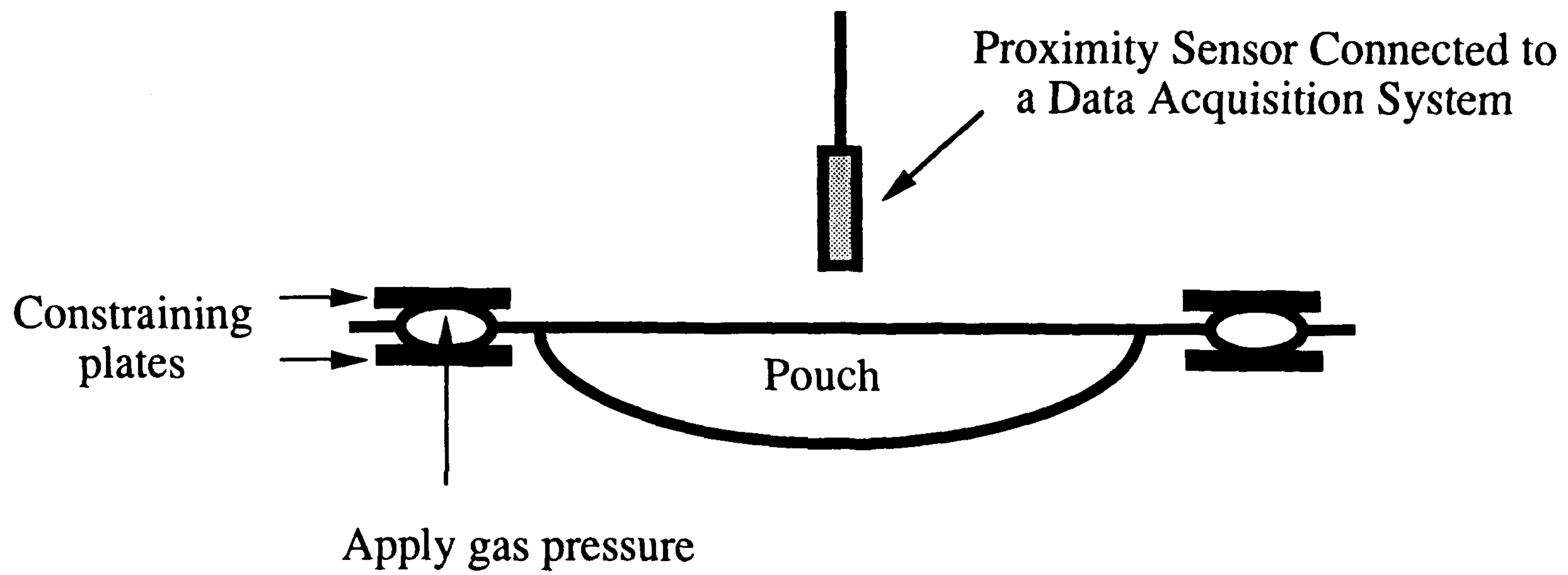


Figure 3. Light Sensor Unit



This technique may be used to detect pinholes in empty packages made of foil material, such as the pouch shown here. Light can easily pass through pinholes as small as 10 μm. An in xpensive sensor can detect light penetration within a fraction of second.

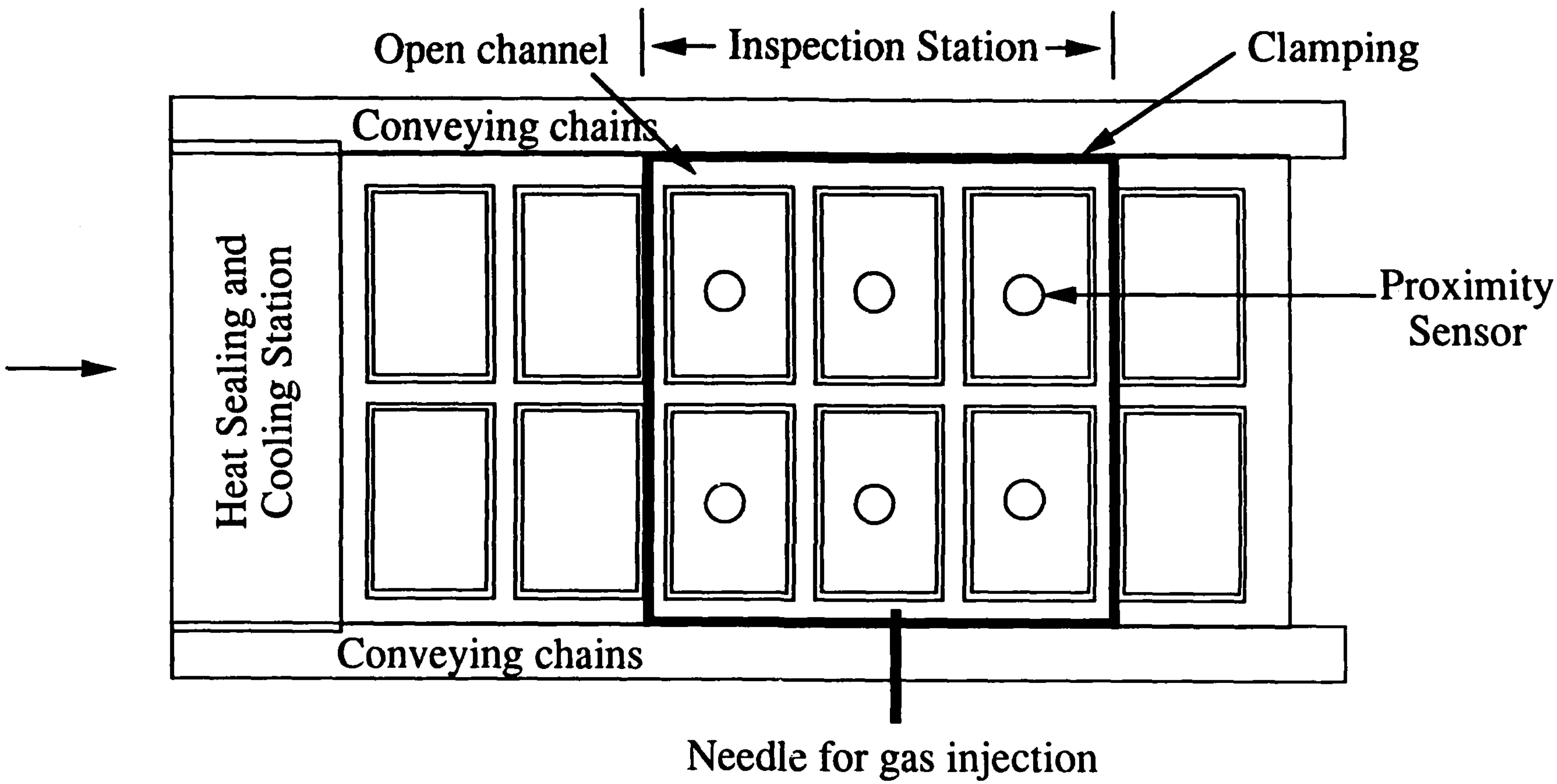
Figure 4
Detecting Leaks and Testing Seal Strength



Compressed gas is applied through the channel surrounding the seal of the pouch. There are two purposes of using this technique. The first purpose is to detect leaks in the seal. If there is a leak or leaks, the gas will go into the pouch and cause pouch to move slightly. The movement will be detected by the proximity sensor. The second purpose is to test the seal strength. If the seal is weak, the gas will also go into the pouch and cause the pouch to move, and the movement of the pouch can be detected by the proximity sensor. The gas pressure and the distance between the two constraining plates are variables that can be used to manipulate the testing conditions.

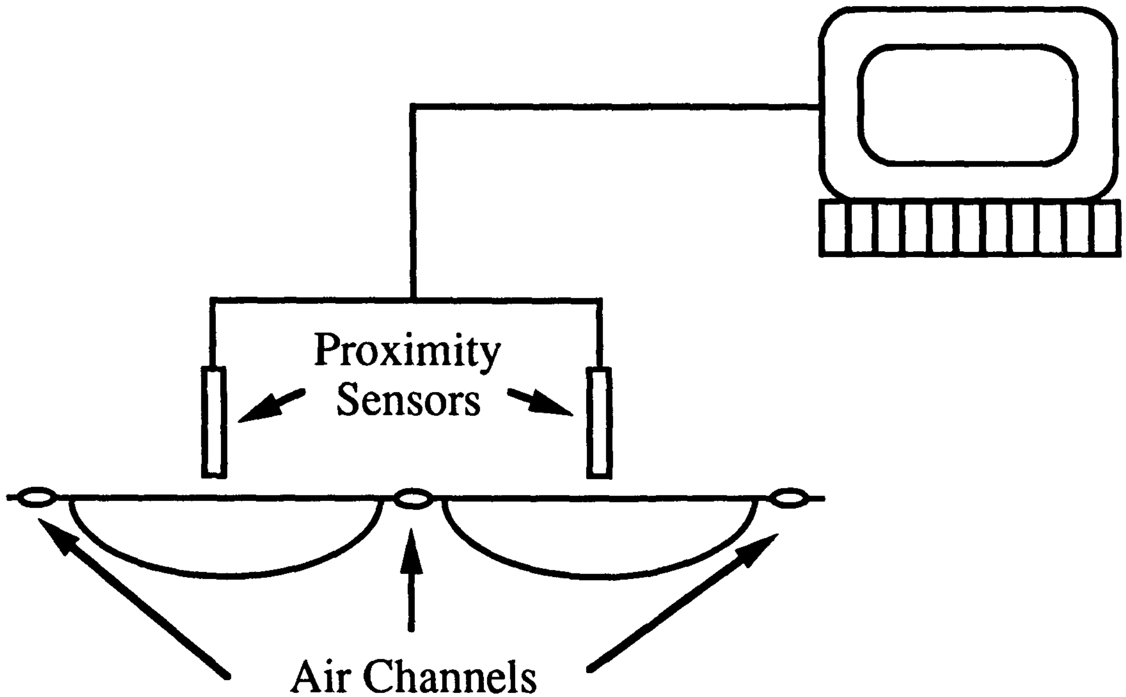
Figure 5

On-Line Leak and Strength Evaluation in an HFFS MRE Pouch Machine



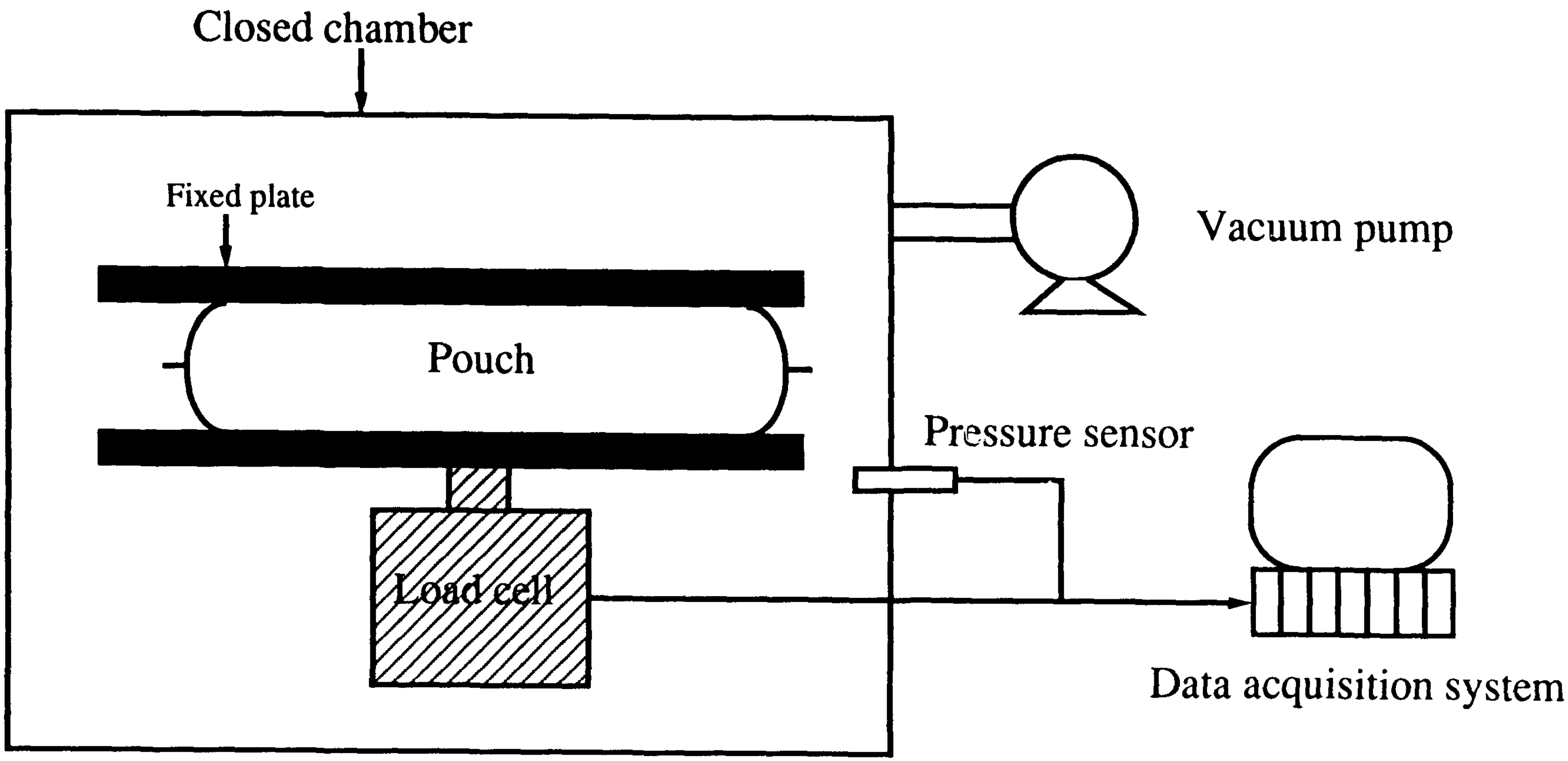
The above diagram shows a section of horizontal-form-fill-seal pouch machine, which is operated with intermittent mode and consists of six pouches per index. After heat sealing and cooling the seals, six pouches are moved to the inspection station where they are clamped. The clamping is designed such that a open channel created around the pouches. The channel can be inflated with compressed gas injected through the needle. If there is a leak or leaks in the seal, the gas will go into the pouch and cause the pouch to move slightly. The movement can be detected by the proximity sensor located above each pouch.

Figure 6. Two-Pouch Unit (Top View)



The unit uses the concept described in Figure 4. It is connected to a Seal Analyzer CA2000 by Seal Integrity Corp. The CA2000 measures the deflection of the lids as a function of time.

Figure 7. Vacuum Unit



The operation of the vacuum unit involves placing a pouch between two parallel plates. The upper plate is not moveable, and the lower plate sits on a load cell. The vacuum is used to evacuate the air inside the closed chamber. The pressure differential between the inside and the outside of the pouch cause the pouch to expand and exert force on the load cell. The force exerted on the load cell and the pressure inside the chamber (measured with a pressure sensor) are recorded as functions of time by the data acquisition system.

Figure 8. **Non-leaky pouches have smaller negative slopes than leaky pouches**

The curves below are those for Pouch #115 which has a 50 μm hole. The hole was first covered so that the pouch became nonleaky. Two runs were conducted with the vacuum unit, and the results of the two runs were almost identical. The hole was then removed so that the pouch became leaky. Again two runs were conducted with the vacuum unit. Compared to the nonleaky pouches, the leaky pouches have significantly higher negative slopes. The load force for the second run was lower than that for the first run because some residual gas escape from the pouch during the first run.

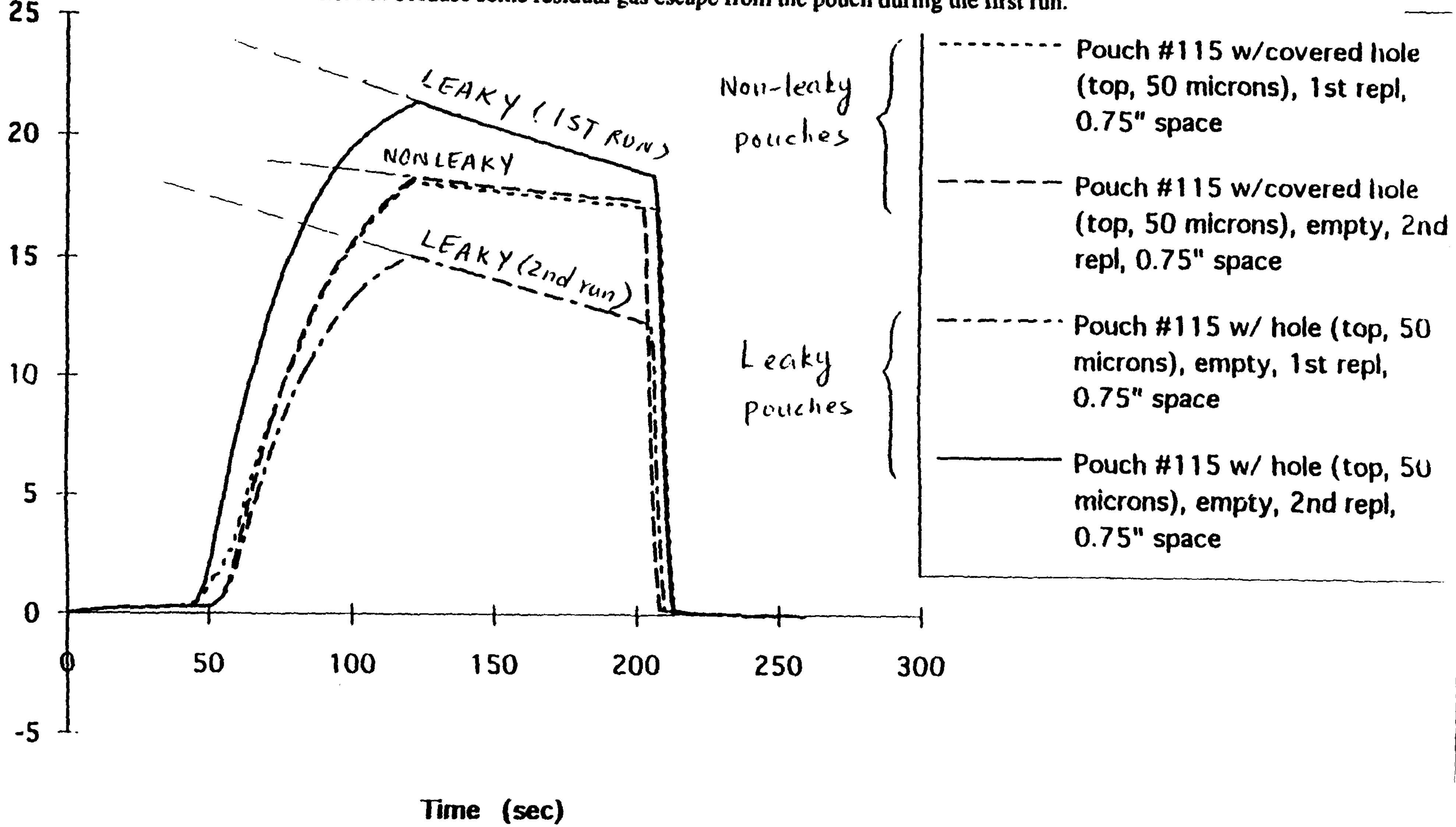


Figure 9. The curves for pouches with a leak of 100 μm in diameter are greatly different from those of pouch with no leak. The pouch is empty.

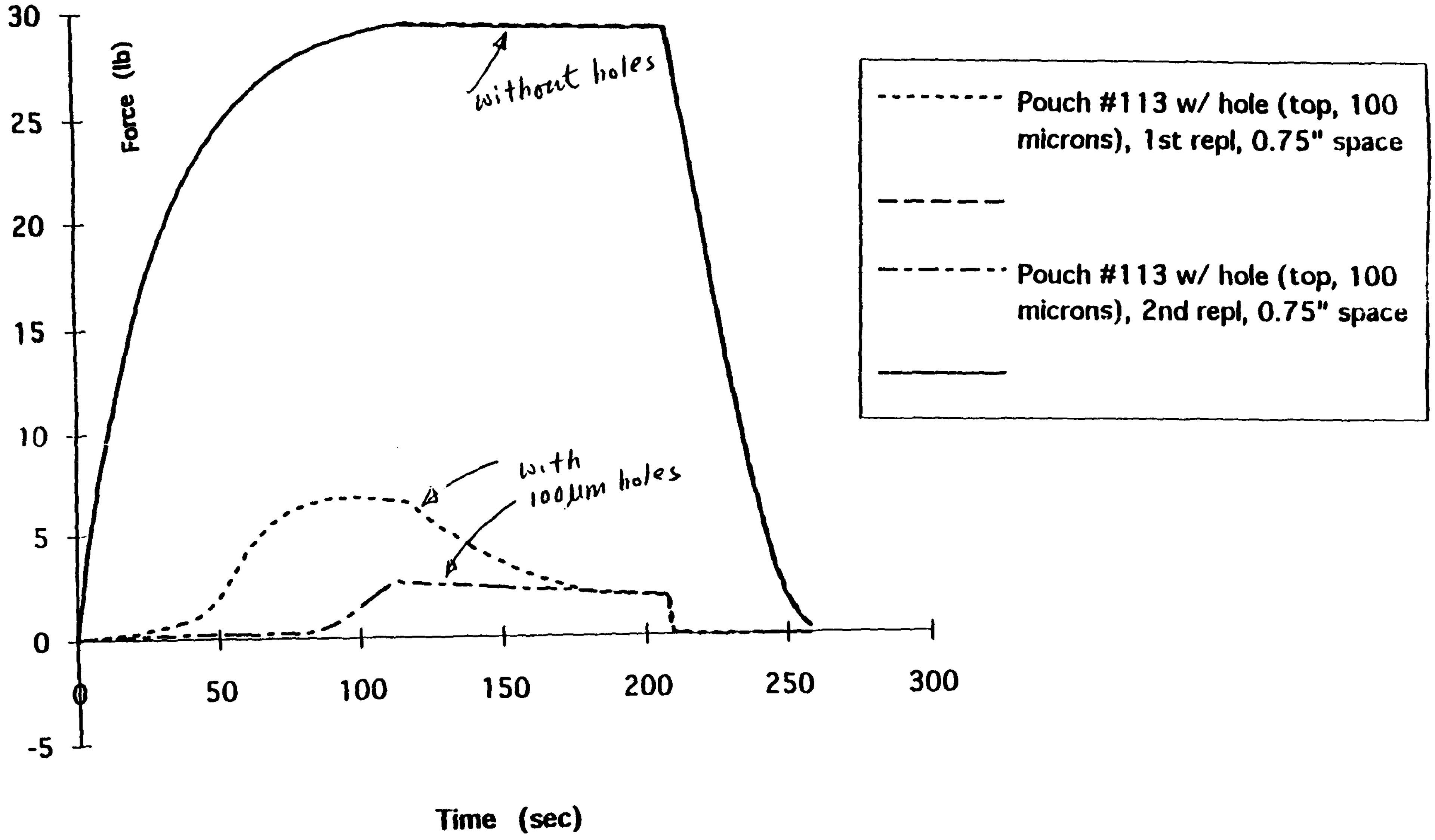


Figure 10. The curves for pouches with a leak of 100 μm in diameter are greatly different from those of pouch with no leak. The pouch is filled with starch solution.

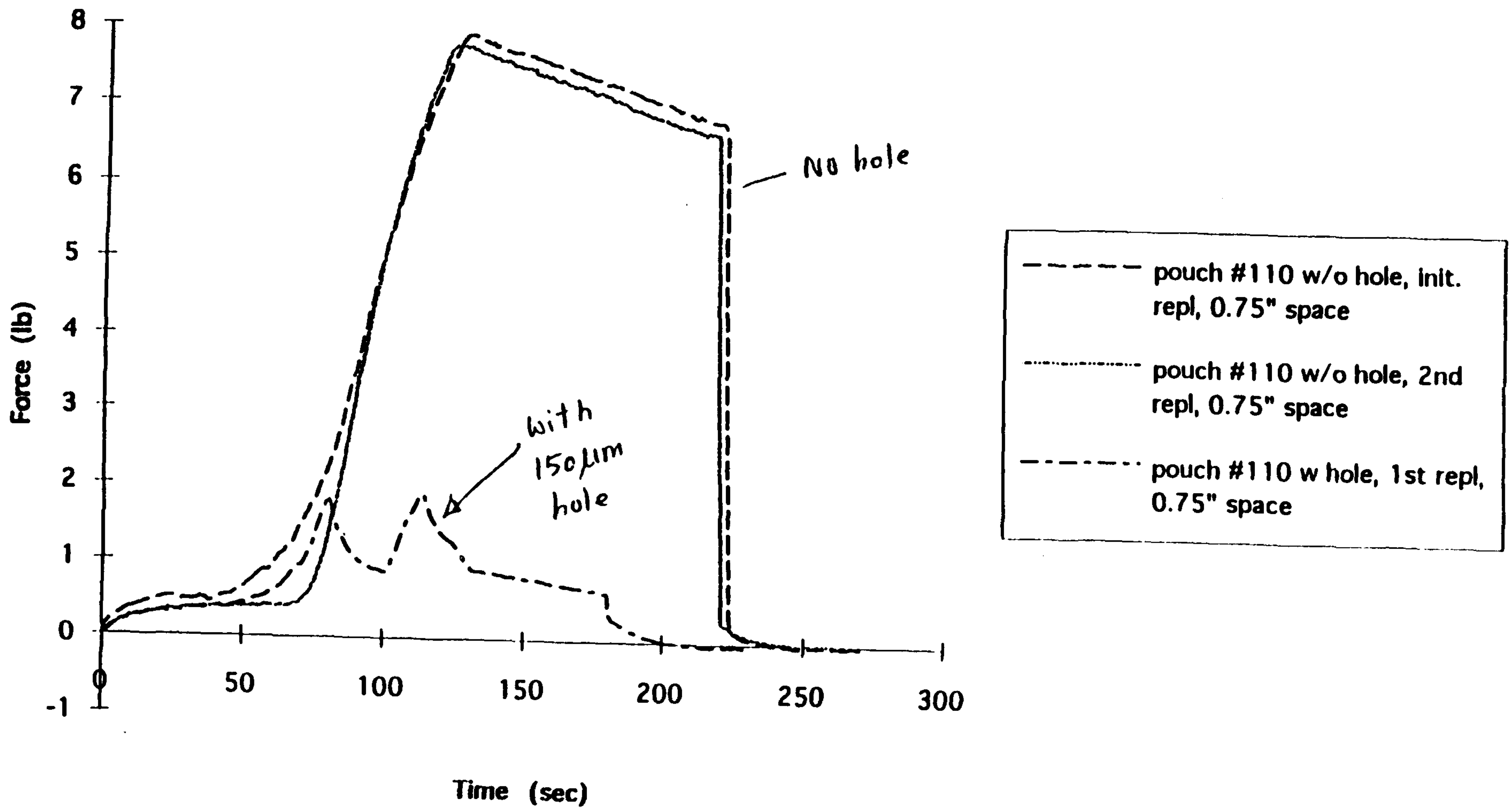


Table 1. Results from the two-pouch unit					
Deflection Set(mil):		2			
Hole Diameter(mil):		8			
Pouch containing:		empty			
Test No	Detect Time	Channel Pressure	Test No	Detect Time	Channel Pressure
	(sec.)	Range(psi)		(sec.)*	Range(psi)
1	0.11	1~15	1	0.11	78~88
2	0.11	1~15	2	0.11	78~88
1	0.22	1~15	1	0.11	78~88
2	0.33	1~15	2	0.11	78~88
1	0.99	1~15	1	0.11	78~88
2	0.37	1~15	2	0.11	78~88
1	1.37	1~15	1	0.11	78~88
2	1.32	1~15	2	0.11	78~88
Max.	1.37			0.11	
Min.	0.11			0.11	
Mean	0.60	8		0.11	83
STDV	0.54			0.00	
Test No	Detect Time	Channel Pressure	Test No	Detect Time	Channel Pressure
	(sec.)	Range(psi)		(sec.)	Range(psi)
1	0.11	55~65	1	0.11	102~110
2	0.11	55~65	2	0.11	102~110
1	0.52	55~65	1	0.11	102~110
2	0.32	55~65	2	0.11	102~110
1	0.27	55~65	1	0.11	102~110
2	0.27	55~65	2	0.11	102~110
1	0.23	55~65	1	0.11	102~110
2	0.11	55~65	2	0.11	102~110
Max.	0.52			0.11	
Min.	0.11			0.11	
Mean	0.24	60		0.11	106
STDV	0.14			0.00	
*0.11 including "very bad"					

Table 1. Results from the two-pouch unit (continuation 1)

Deflection Set(mil):		2			
Hole Diameter(mil):		4.5			
Pouch containing:		empty			

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	0.27	1~15	1	0.11	78~88
2	0.27	1~15	2	0.11	78~88
1	0.33	1~15	1	0.11	78~88
2	0.44	1~15	2	0.16	78~88
1	0.49	1~15	1	0.55	78~88
2	1.32	1~15	2	0.38	78~88
1	1.82	1~15	1	0.38	78~88
2	1.37	1~15	2	0.44	78~88
Max.	1.82			0.55	
Min.	0.27			0.11	
Mean	0.79	8		0.28	83
STDV	0.61			0.18	

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	0.27	55~65	1	0.11	102~110
2	0.27	55~65	2	0.11	102~110
1	0.11	55~65	1	0.16	102~110
2	0.27	55~65	2	0.33	102~110
1	0.39	55~65	1	0.11	102~110
2	0.44	55~65	2	0.27	102~110
1	1.05	55~65	1	0.11	102~110
2	0.99	55~65	2	0.11	102~110
Max.	1.05			0.33	
Min.	0.11			0.11	
Mean	0.47	60		0.16	106
STDV	0.35			0.09	

Table 1. Results from the two-pouch unit (continuation 2)

Deflection Set(mil):	2
Hole Diameter(mil):	4.5
Pouch containing:	8 oz water

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	1.25	1~15	1	0.27	78~88
2	1.15	1~15	2	0.27	78~88
1	2.25	1~15	1	0.55	78~88
2	2.09	1~15	2	0.49	78~88
1	3.10	1~15	1	0.55	78~88
2	2.99	1~15	2	0.49	78~88
1	1.18	1~15	1	0.55	78~88
2	1.37	1~15	2	0.55	78~88
Max.	3.10			0.55	
Min.	1.15			0.27	
Mean	1.92	8		0.47	83
STDV	0.81			0.12	

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	0.27	55~65	1	0.27	102~110
2	0.27	55~65	2	0.27	102~110
1	1.05	55~65	1	0.33	102~110
2	0.69	55~65	2	0.49	102~110
1	0.55	55~65	1	0.55	102~110
2	0.80	55~65	2	0.49	102~110
1	0.79	55~65	1	0.79	102~110
2	0.68	55~65	2	0.65	102~110
Max.	1.05			0.79	
Min.	0.27			0.27	
Mean	0.64	60		0.48	106
STDV	0.27			0.19	

Table 1. Results from the two-pouch unit (continuation 3)

Deflection Setting (mil):	0.5
Hole Diameter (mil):	1
Pouch containing:	empty

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	1.32	1~15	1	0.88	78~88
2	2.58	1~15	2	0.38	78~88
1	5.99	1~15	1	4.89	78~88
2	12.85	1~15	2	4.78	78~88
1	2.36	1~15	1	0.66	78~88
2	3.13	1~15	2	0.60	78~88
1	3.57	1~15	1	0.55	78~88
2	1.48	1~15	2	0.99	78~88
Max.	12.85			4.89	
Min.	1.32			0.38	
Mean	4.16	8		1.72	83
STDV	3.80			1.93	

Test No	Detect Time (sec.)	Channel Pressure Range(psi)	Test No	Detect Time (sec.)	Channel Pressure Range(psi)
1	0.66	55~65	1	0.44	102~110
2	0.60	55~65	2	0.33	102~110
1	5.49	55~65	1	1.81	102~110
2	8.62	55~65	2	1.87	102~110
1	0.71	55~65	1	0.44	102~110
2	0.77	55~65	2	0.60	102~110
1	0.82	55~65	1	0.71	102~110
2	0.82	55~65	2	0.77	102~110
Max.	8.62			1.87	
Min.	0.60			0.33	
Mean	2.31	60		0.87	106
STDV	3.05			0.62	

Appendix 4.1

A review of leak detection principles and systems (TWP 60)

COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

On-Line Inspection System and Testing Method for Pouch Integrity for an Automated Combat Ration Manufacturing Facility
Technical Working Paper (TWP) 60

A Review of Leak Detection Principles and Systems

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I. Introduction

The objective of STP-7 is to determine the feasibility of developing an on-line, non-destructive system for inspecting MRE pouches. Specifically, the inspection is aimed at detecting leaks, excessive pinholes, and weak seals. This technical paper is a review of the principles and commercially available systems for leak detection of packages, particularly those that may be applicable to MRE pouches. In additional to literature search, the information here was gathered through personal contacts with many vendors (such as Taptone, Modern Control Inc., and Container Integrity Corp.) as well as with experts (such as those from the School of Packaging at Michigan State University and from Purdue University) in the field of nondestructive package testing.

II. General Considerations

The first important consideration is the determination of the "minimum leak size" to be detected or the sensitivity of the leak detection system. There is no hard and fast answer to the question of how small a leak should be detected. Theoretically, microbes may be as small as 0.5 micron in diameter. Detecting 0.5 micron or smaller microholes is often expensive and difficult, especially when the time allowable for testing is very short, for example during on-line inspection. In practice, the minimum leak size may be set to much higher than 0.5 micron. Based on the results of several studies,[1-3] it is unlikely that microbes will penetrate pinholes of less than 20 microns in diameter and micro-channels of less than 30 microns, even under accelerated conditions. Using these sizes is a good guideline for establishing the minimum leak sizes for MRE pouches.

Since leak sizes, especially for micro-channel leaks, are difficult to measure and most leaks involve gas flow, leak rates are often measured in terms of amount of gas flow per time.[4] A common unit for leak rate is "cubic centimeters of gas (at standard temperature and pressure) per second" or "std cc/sec". The larger the leak rate, the larger is the size of the leak. Leak rate is also used as a measure for the sensitivity of leak detection systems; for example, the sensitivities for the bubble test is 10^{-4} std cc/sec, for the dye penetrant test is 10^{-6} std cc/sec, and for the helium mass spectrometer test is 10^{-11} std cc/sec. The sensitivity required for MRE pouches is estimated to be between 10^{-5} and 10^{-6} std cc/sec.

The second consideration is the maximum allowable time for leak detection. For the HFFS machine developed by CRAMTD, the allowable time for detection is limited to about 3 seconds per index. The smaller the leak, the longer is the time required for leak detection. Thus a viable leak detection system must be sensitive enough to detect the minimum leak size and fast enough to perform the detection within the allowable time.

The third important consideration is the sources and locations of leaks. For MRE pouches, the sources of leaks are pinholes and breaks in the foil, seal contamination, improper heat sealing, mishandling, etc[5]. The stretching forming of the newly developed HFFS process may also causes additional foil thinning and pinholes formation. Leak defects in the body of a MRE pouch are pinholes and foil breaks, and leak defects in the seal area are gross leaks or micro-channel leaks. It may be desirable to isolate the body and the seal area so that each part can be tested with a different method.

The fourth important consideration is the type of food contained in the pouch. Leaks in packages containing dry and porous foods are much easier to detect than those in packages containing wet foods. The problem with wet foods is that moisture inside the package may plugged up possible leaks, making detection of these leaks very difficult. Unfortunately most commercially available leak detection systems are suitable only for dry and porous foods.

The fifth important consideration is the adaptability and cost of the leak detection system. The leak system should be easily adapted to the existing and the newly developed pouch forming operations, and the cost of the system should not be too high.

III. Leak Detection Principles

1. Pressure Differential Techniques

This is the most popular technique for detecting leaks in food packages. When there exits a pressure differential across the wall of a package, any possible leak will cause a gas (such as air or nitrogen) to flow in or out of the package. An observed gas flow is an indication of the existence of a leak or leaks. There are two common methods for detecting air flow: (1) by measuring pressure changes using a very sensitive pressure sensor, and (2) by measuring deflections of the package wall due to the gas flow using a proximity sensor.[6]

The pressure differential can be classified into the vacuum method and the external pressure method. In the vacuum method, a package is placed inside an enclosed chamber where a vacuum is drawn to create a pressure differential across the package wall. The pressure inside the package is approximately one atmosphere, and the pressure outside the package is lower depending on the extent of vacuum drawn. Thus the residual gas inside the package will expand, and if leaks exist in the package, the residual gas may escape through these leaks. The vacuum method requires that residual gas must exist in the package and that the residual gas must be able to travel freely in the package. The

major problems of this method is its low effectiveness of detecting leaks of packages containing wet foods. The moisture inside the packages may plugged up possible leaks, and because the pressure differential is low (less than one atmosphere), air may not be able to flow through these leaks, making detection not possible.

In the external pressure method, a package is placed into an enclosed chamber where a high external pressure is applied. Again the pressure inside the package is approximately one atmosphere, but the pressure outside the package could be rather high (say, up to 7 atmospheres). This method does not require residual gas to be present in the package. Compared to the vacuum method, this method requires shorter test time and can detect smaller leaks because the pressure differential is much higher.

The sensitivity of the pressure differential methods varies widely (10^{-3} to 10^{-6} std cc/sec), depending on the whether the vacuum method or the external pressure method is used, the pressure differential, the type of gas used, and the time allowed for testing.

2. Tracer Technique

This technique used a gas such as helium and carbon dioxide as a tracer. The tracer gas is usually injected into the package during sealing. The vacuum technique is often used to force the tracer gas to escape through any possible leak. The presence of helium in the chamber is detected with a mass spectrometer, and the presence of carbon dioxide is detected with a infrared sensor.

The major advantage of this technique is its high sensitivity (10^{-11} std cc/sec). The disadvantages are: (1) the time for testing is often long, (2) a tracer gas must be injected into the package prior testing, (3) the sensors are very expensive, (4) the pressure differential created by the vacuum technique may not be great enough to force through plugged microholes, (5) the tracer gas may escape during retorting, making the technique useless for post-retort testing.

3. Infrared Radiometric and Ultrasonic Scannings

A major cause for leak is seal defects. During the late 1960's and the early 1970's, Natick Laboratories developed a prototype nondestructive machine using infrared radiometric scanning to detect seal defects such as contamination, voids, and wrinkles.[7] Although the machine was proven to be feasible and reliable, but its cost was high at that time. In our laboratory, we have shown that seal defects can also be detected by an ultrasonic scanning technique. However, the major drawback of these techniques are that

they scan only one seal side at a time and is not easily modified to scan all four seal sides of a pouch simultaneously.

4. Miscellaneous Techniques

Other techniques such as optical, thermal conductivity, chemical, and radioisotope methods are also used in other fields. However, it is unlikely that these techniques is suitable for detecting leaks in MRE pouches.

IV. Vendors of Leak Detection Systems

There are available commercially several systems for package integrity testing. Described below are some of the more important ones. All of them are bench-top off-line test station, except the on-line test unit manufactured by Wilco.

1. TapTone (a division of Benthos Inc., North Falmouth, Massachusetts)

This company produces several nondestructive units for evaluating package integrity. One of them is the Seal Integrity Tester (SIT) used for inspecting seal integrity of containers with flexible lids. High external pressure (up to 7 atmospheres) is forced against the seal junction of the container during testing. The movement of the lid is monitored with a proximity sensor, and a tiny movement of the lid indicates a seal leak.

The company also produces a system, the Puffer, for inspecting plastic cups and trays with flexible membrane lids. Heat is applied to container headspace, and a proximity sensor is used to monitor the lid movement. If no leaks are present, a convex curvature of the lid will result. Since the pressure exerted by the expansion of headspace gas is low, the Puffer has lower sensitivity than the Seal Integrity Tester.

2. Modern Control Inc. (Minneapolis, Minnesota)

The company produces two off-line units for testing package integrity. The first unit, Pac-Guard 400, uses CO_2 as a tracer gas, and an infrared sensor to detect any escape of CO_2 through pinholes or cracks in the package. The unit uses the vacuum technique by placing a package in a test fixture and rapidly drawing a vacuum in the fixture. After a preset dwell time, ambient air is rush back into the fixture, sweeping any accumulated CO_2, and the air is sent to the infrared sensor for analysis. The test is nondestructive and can detect leak rates of 10^{-3} std cc/sec. However, the disadvantage of this unit are that it requires CO_2 be presented in the headspace of the package. Because the unit uses the vacuum technique, it is not suitable for detecting micro-channel leaks of packages

containing wet food. Also CO_2 may leak out of the package during retorting, making the post-retort testing unreliable.

Recently the company introduces a Model 1520S MOCON/SKYE Package Test System, which tests for both leaks and seal strength of packages. The unit operates on pressure decay principle. However it is an off-line, destructive unit, and the testing requires approximately 30 seconds to perform. The unit is also not suitable for testing package containing liquid food.

3. Wilco Precision Test (Tuckahoe, New York)

This company produces a series of machines (Wilcomat Series) for on-line nondestructive leak detection for aseptic cups and trays. This system use a pressure differential approach which involves a three stage testing protocol: (1) applying external pressure or vacuum on the package, (2) allowing time for the pressure to stabilize, and (3) testing. The testing phase measures pressure decay using a pressure sensor. However, the machines have not been demonstrated to be able to detect leaks in pouches containing wet foods.

4. Container Integrity Incorporated (Richland, Washington)

This company produces an off-line nondestructive test unit (CA2000 Seal Analyzer) for detecting channel leaks in the seal area of a container. Similar to the Modern Control's Seal Integrity Tester, this unit detects micro-channel leaks in the seal using the external pressure technique. Its unique feature is the use a clamping device to create an enclosed channel around the seal area where high external is applied, thus allowing higher sensitivity to be achieved. However, modification of the container design may be necessary to allow for the clamping.

5. Other Vendors

Other venders such as ARO Corporation and Varian Associates also produced leak detection systems which are mostly off-line and destructive. We also contacted several other venders but found that they were no longer in business.

V. Conclusion

We have not found a commercially available system that can be used directly for on-line nondestructive leak detection of MRE pouches containing liquid foods. Based on this review, we feel that the most promising approach for developing a viable leak detection

system involves two steps: (1) testing for pinholes and foil breaks in the body, and (2) testing for leaks in the seal area. The external pressure technique is best for detecting leaks in the seal area.

VI. References

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Appendix 4.2

Assessing Package Integrity

A paper presented at "Global Aspects of Packaging Conference"
at Orlando, February 24-26, 1993

Assessment of Package Integrity

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Assessing package integrity is a critical step to assure the safety and quality of food and pharmaceutical products. The common package defects are weak seals, contaminated seals, leaks, cracks, and pinholes. These package defects may lead to significant loss of product quality, loss of consumer confidence, and in some cases microbiological risks.

With the proliferation of flexible plastic packages, such as those used for thermoprocessed foods and aseptically processed foods, the need for package integrity inspection has become even more important. Compared to metal cans and glass bottles, these plastic packages are much more prone to seal defects. Leaky seals and weak seals are often found to be the major causes for post-process contamination and microbial spoilage for these packages. The problem is aggravated by the fact that detecting these defects is difficult and often requires creative approaches.

An effective program for assuring package integrity should include a plan for prevention and a plan for inspection. The idea of the plan of prevention is to minimize the occurrence of package defects with careful plant design, employee training, package material inspection, control of filling and sealing process, and so on. The plan tor inspection involves integrity testing of finished packages which may be performed off-line or on-line, manually or automatically, destructively or nondestructively.

To design an effective inspection program, many questions such as those listed below are to be answered. What are the major defects expected of the package? Where are these defects likely to occur in the package? What are the causes of these defects? What is the likelihood of these defects to occur during processing, distribution, and handling? What is the seal strength requirement of the package? What techniques are to be used to test the performance of the package? Is the testing to be performed off-line or on-line, manually or automatically, destructively or nondestructively, using statistical process control (SPC) or 100% inspection?

The seal of a package is a critical area where leaks are frequently found. An important issue is what minimum leak size is to be detected for the package. There is no hard and fast answer to this issue. Microbes are as small as 0.5 micron in diameter, and detecting micro-leaks of this size is expensive and difficult, especially when the time allowable for testing is very short, for example during on-line inspection. Based on the results of several published studies, it is unlikely that microbes will penetrate pinholes of less than 20 microns and micro-channels of less than 30 microns, even under severe conditions. For most practical purposes, a detection system may be considered adequate if it can detect leak sizes of 20 microns.

Techniques for package integrity inspection are often classified as destructive and nondestructive. The most commonly used and also the simplest of nondestructive techniques is visual inspection by human for voids, wrinkles, delaminations, contaminated seals, etc. Other commonly used package integrity inspection techniques are destructive, including the dye penetration test, burst test, seal strength test, microbial challenge test, etc.

There are several nondestructive techniques for inspecting package integrity. The effectiveness of these techniques depend on the kind of product (solid or liquid), amount of headspace, package shape and size, leak size, time allowed for inspection, etc. Pressure difference is the most popular technique for detecting leaks in food packages. When there exits a pressure differential across the wall of a package, any possible leak will cause a gas (such as air, nitrogen, or hydrogen) to flow in or out of the package. An observed gas flow is an indication of the existence of a leak or leaks. There are two common methods for detecting air flow: (1) by measuring pressure changes using a very sensitive pressure sensor, and (2) by measuring deflections of the package wall due to the gas flow using a proximity sensor. Other nondestructive techniques include the use of machine vision, tracer gas, infrared radiometry, ultrasonic scanning, etc.

Presently, few companies have the capability of inspecting every package in their production lines. A common practice for assuring package integrity is to inspect a

small portion of packages from the production off-line by human using some destructive tests. This practice requires intensive labor and a significant product loss for the destructive tests. A better approach is to use an automated on-line nondestructive system to provide the benefits of: (1) eliminating of the need of manual inspection, (2) eliminating product loss due to destructive tests, (3) providing the possibility of 100% inspection, and (4) providing immediate feedback for process control.

Developing on-line package integrity inspection systems is a challenging task, and very few of these systems are available in the market. The basic considerations for selecting an on-line system are sensitivity, repeatability, speed, and cost. For leak detection, the smaller the leak, the higher sensitivity and the longer the detection time are required. The requirement for speed is determined by the throughout of production. A high speed production line allows little time for inspection for each package, and therefore the response of the inspection system must be very fast. Cost is certainly an important factor to be considered careful. On-line inspection systems are expensive, but the benefits may justify the cost.

In conclusion, package integrity is a critical step in quality assurance programs. Selecting an effective package integrity assurance program requires careful thoughts about the package design, processing, distribution and handling, and cost. In the highly competitive market, no company can afford to distribute leaky and defective packages.

Motivations for Package Integrity Inspection

- Avoid microbial spoilage and reduce health risk.
- Avoid economic loss.
- Ensure product quality. Leaker infection and breakage are the two commonest form of package failure leading to quality loss.

Needs For Package Integrity Assessment

- A critical step in QA/QC.
- Package defects may lead to loss of product quality, loss of consumer confidence, and health risks.
- Needs for thermoprocessed foods and aseptic foods, particularly for those that are low-acid.
- Plastic packages such as containers and pouches are more prone to seal defects, and these packages are difficult to inspect.

Quality

- Total Quality Management (TQM)
- Quality is job # 1
- Quality circle
- Statistical quality control (SPC)
- Zero-defects programs
- Hazard Analysis and Critical Control Point (HACCP)

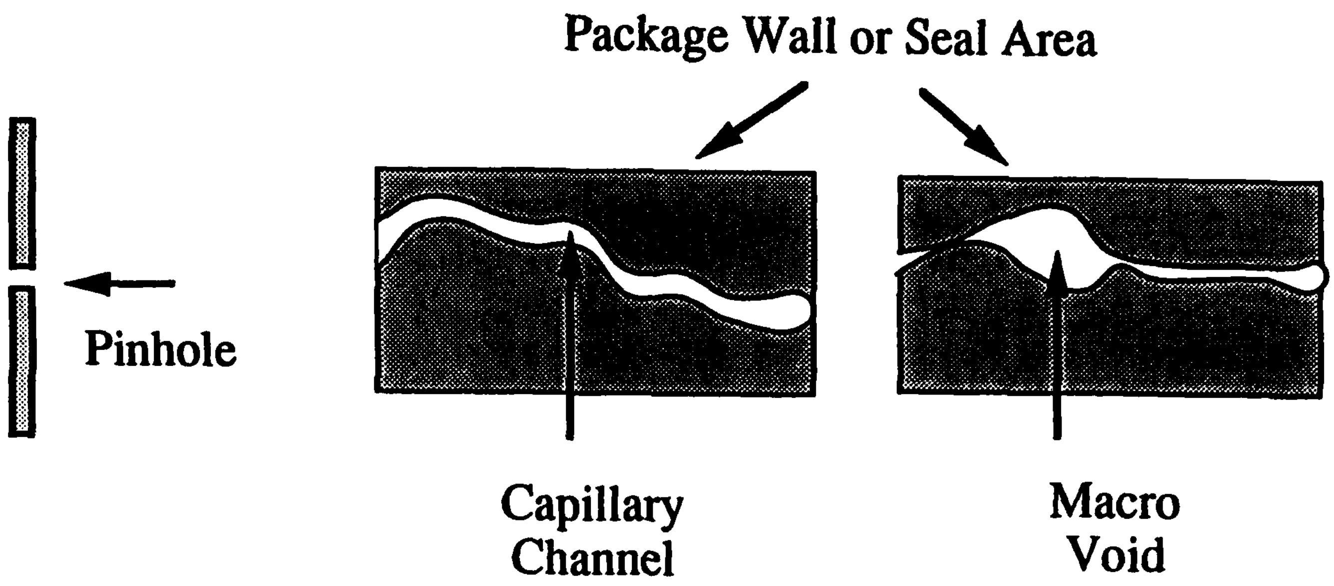
Total Quality Management

- Product planning, marketing, and sales
- Process development
- Manufacturing
- Employee training
- Inspection and testing
- Customer services

Common Package Defects

- Weak seals and contaminated seals
- Leaks, cracks, and pinholes
- Wrinkles, delaminations, surface defects
- The two important factors to be considered in package inspection are leaks and strength.

SOME PACKAGE DEFECTS



Pinholes and channel leaks in the seal are the two common package defects. Oxygen and moisture can penetrate through these defects into the package leading to quality loss of sensitive foods. A bigger concern is the penetration of microbes which may lead to health risk. Because of longer depth, channel leaks are more resistant to penetration.

Common Causes for Package Defects

- Poor sealing
- Mishandling
- Seal contamination
- Retorting

Package Integrity Inspection Program

- Plan for prevention
  - To minimize the occurrence of package defects with careful package design, plant design, employee training, package material inspection, process control (filling and sealing) etc.
- Plan for inspection
  - To inspect finished packages off-line or on-line, manually or automatically, destructively or nondestructively.

Basic Considerations for Integrity Inspection

- What is the stability of the product?
- What is the form of the product? Dry or liquid product?
- What kind of packages are used? Glass, metal, or plastics? Containers, bottles, pouches?
- What are the seal strength requirement of the package?

Basic Considerations

- What are the major and minor defects of the package?
- Where are these defects likely to occur in the package?
- What are the causes of these defects?
- What is the likelihood of these defects to occur during processing, distribution, and handling?

Basic Considerations

- What techniques are to be used to test the package?
- Are empty packages, finished packages, or both are to be inspected?
- Is the testing to be performed off-line or on-line, manually or automatically, destructively or nondestructively?
- Is statistical process control (SPC), 100% inspection, or a combination of the two to be used?

Basic Considerations

- What is the required response time of the inspection system? What is the rate of production?
- What is the requirement for sensitivity of the inspection system?
- How much can we afford to spend on package integrity inspection? What is the cost for not inspecting the package?

What Minimum Hole Size to Inspect?

- There is no definitive answer to this issue.
- Microbes are as small as 0.5 micron in diameter, and viruses are even smaller.
- Detecting very small micro-leaks of this size is expensive, difficult, and requires a long time.
- For most cases, a leak detection system is adequate if it can detect pinholes of less than 10 microns and micro-channels of less than 30 microns.

Automated On-line Nondestructive Inspection

- Eliminate human error and save on labor cost.
- Eliminate product loss due to destructive tests.
- Increase confidence with 100% inspection.
- Provide immediate feedback for process control.

Basic of Inspection Systems

Stimuli → Food and Package → **Response**

Stimuli

Heat
Gas
Tracer
Electromagnetic waves
Ultrasound
etc.

Response

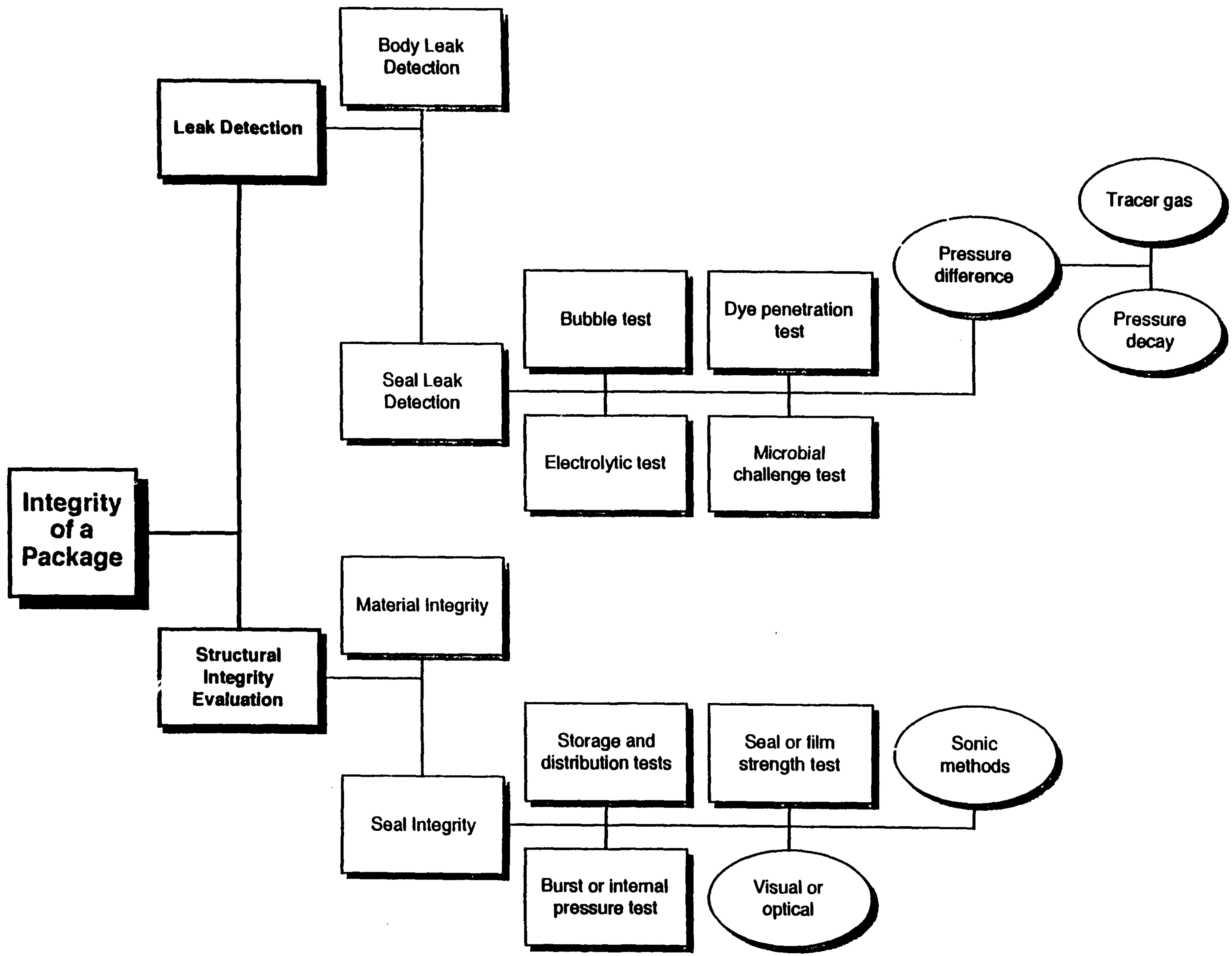
Pressure change
Heat flux change
Package movement
etc.

Driving Force — Sensor

Most inspection systems involve a stimuli and a response. Both should be sufficiently strong, and the intensities of them depend on the characteristics of the food and the package. To illustrate the concept, consider the technique of using pressure differential for leak detection. The stimuli is the amount and rate of gas flow in the package, which depend on the pressure differential driving force and the resistance of the leak. The response may be pressure change or deflection of the package. A good sensor, such as pressure sensor or proximity sensor, is needed to detect the response.

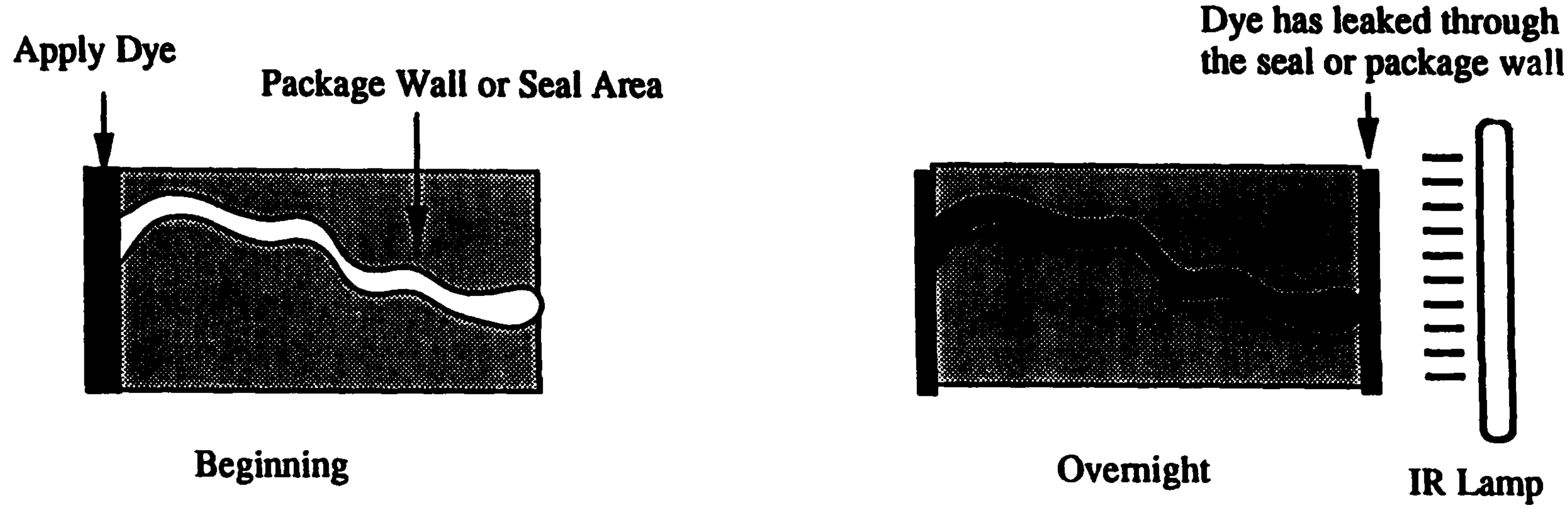
Package Integrity Inspection Techniques

- Visual inspection
- Burst test
- Tensile test
- Dye Penetrant test
- Biotest
- Etc.



Integrity of a Package
Leak Detection
Body Leak Detection
Seal Leak Detection
Bubble test
Electrolytic test
Dye penetration test
Microbial challenge test
Pressure difference
Tracer gas
Pressure decay
Structural Integrity Evaluation
Material Integrity
Seal Integrity
Storage and distribution tests
Burst or internal pressure test
Seal or film strength test
Visual or optical
Sonic methods

DYE PENETRANT TEST

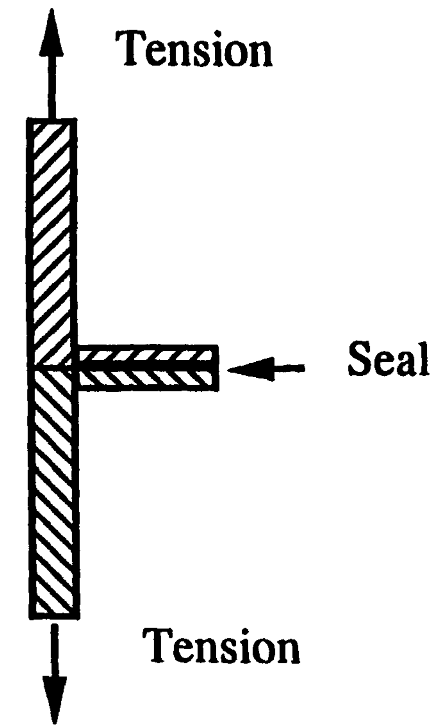


Operation: A dye (such as a solution of 0.5% Rhodamine B in propanol) is applied to critical areas especially the seals of packages. Any pinhole or channel leak may be detected by observing the penetration of the dye.

Advantages: Pinholes or channel leaks as small as 10μm may be easily detected. The technique is simple and inexpensive to perform.

Disadvantages: The technique is destructive, time consuming, and labor intensive.

Tensile Seal Strength Test or Peel Test



Operation: The seal of a sample strip is separated by pulling it apart with an instrument such as an Instron Universal Tester. The maximum load per seal width is taken as the seal strength.

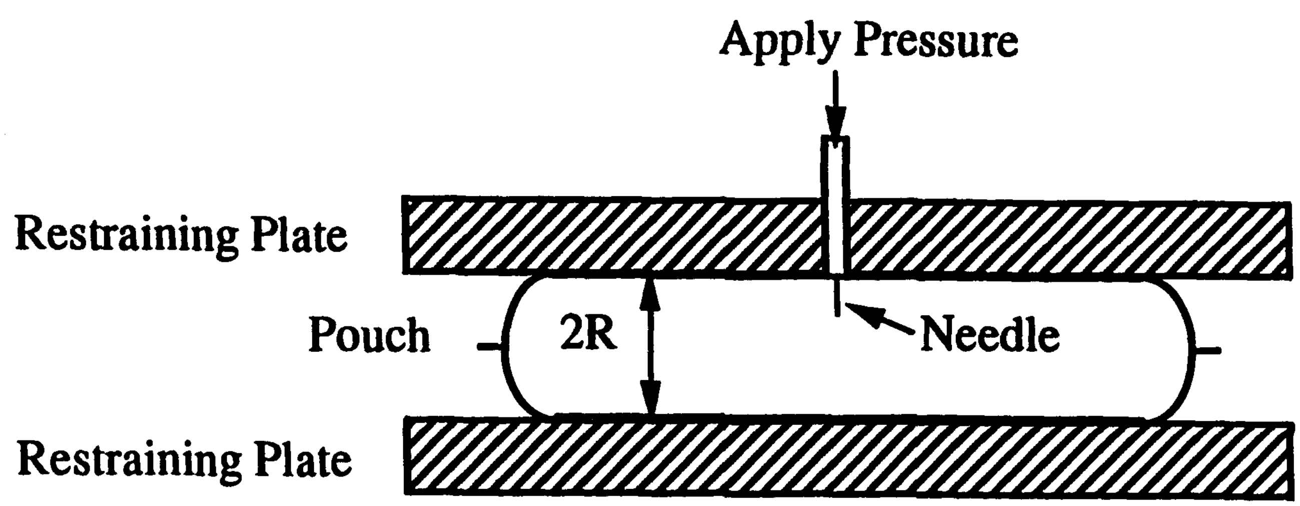
Advantages: It is simple and well documented as a ASTM standard.

It can be used for evaluating seal strength for both incoming material and finished packages.

Disadvantages: The technique is destructive, time consuming, labor intensive, and requires the use of a rather expensive instrument such as the Instron Universal Tester.

To test the strength of package, such as a pouch, it is often necessary to perform the tests on all four sides of the package.

Burst Test



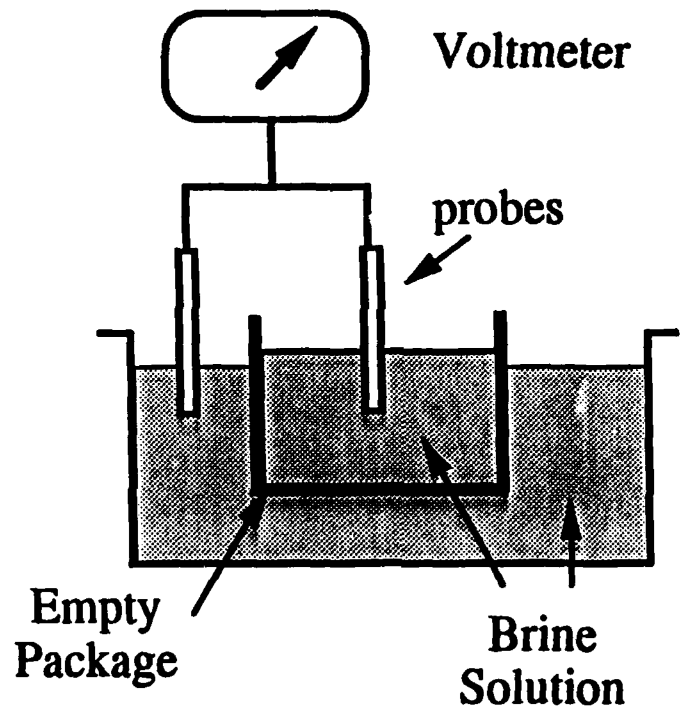
STRENGTH = PRESSURE X R

Operation: A package, in this case a pouch, is sandwiched between two parallel plates. A needle is used to puncture the top of the package, and compressed air is injected into the pouch at a predetermined rate. The pressure at which the package ruptures is recorded as the burst pressure.

Advantages: It is a simple, inexpensive and well established technique for evaluating the strength of the entire package

Disadvantages: The technique is destructive, time consuming, labor intensive.

Electrolytic Test

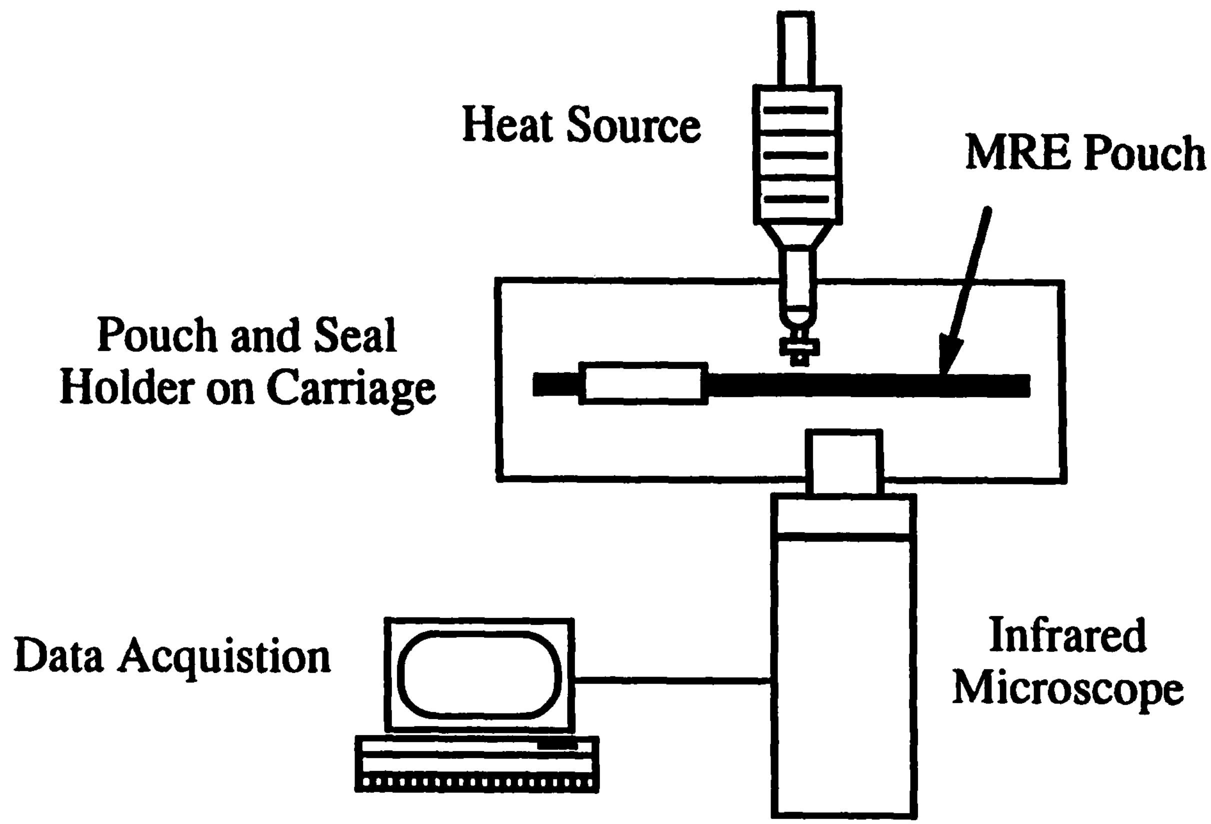


Operation: An empty package is immersed in brine solution. Any leak in the package allows current to flow through the voltmeter to signal a positive test. Higher sensitivity may be achieved by increasing the voltage.

Advantages: It is simple and inexpensive to perform.

Disadvantages: The technique may also be used for finished packages. However the package must be cut and the product inside be emptied before the testing.

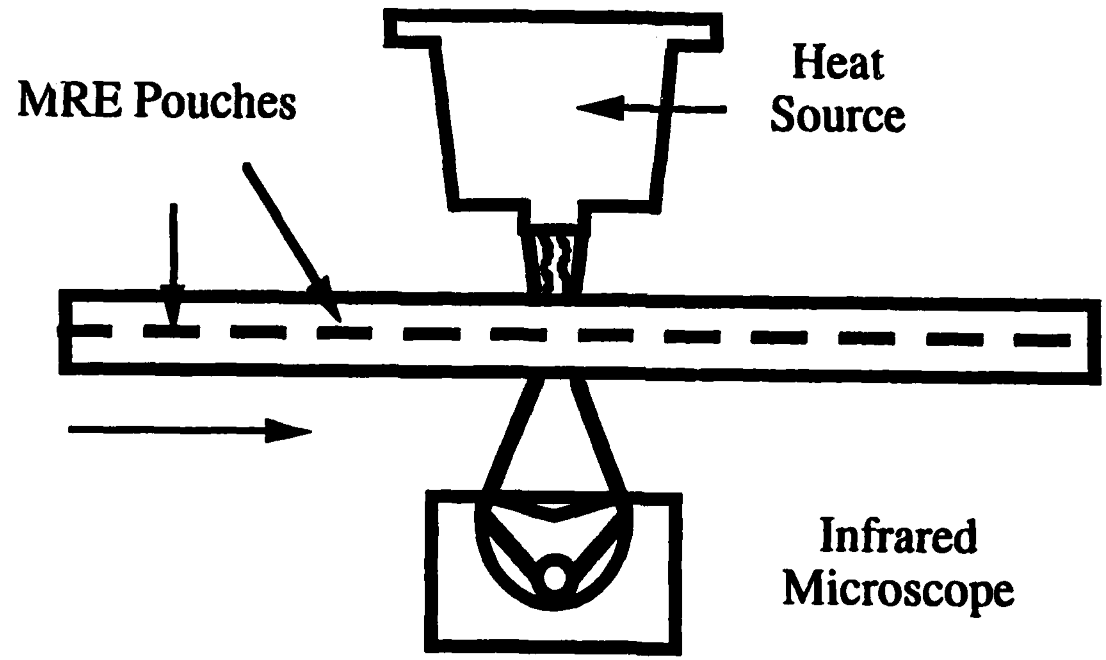
IR Radiometric Microscopy for Determining Seal Defects



This technique was developed by Dr. Rauno Lampi of the US Army Natick Research Laboratory during the late 1960's and the early 1970's. Its function is to perform on-line scanning for food contamination, wrinkles, voids, etc. in the seal areas of MRE pouches.

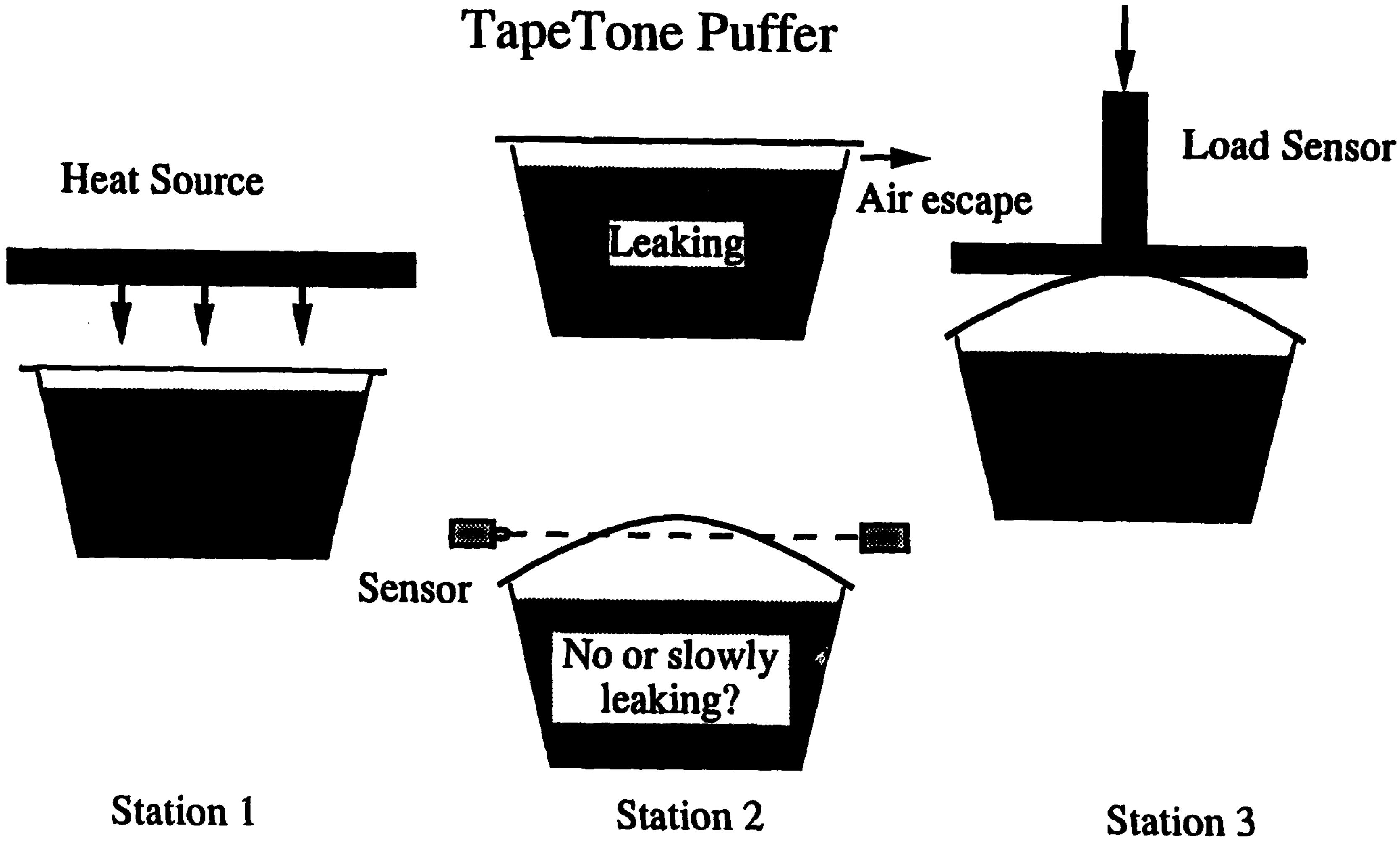
A heat source generates a heat flux to scan the seal of a MRE pouch as shown. An infrared microscope measures the heat flow across the seal, and the amount of heat flow is used to determine if there is food contamination or a void in the seal.

IR Radiometric Microcopy Technique for on-line application



The above diagram shows that MRE pouches are moving to the right on the conveyor. The closure seals pass between a heat source and an IR microscope. Clean seals result in steady heat flux recorded by the IR microscope. A contaminant in the seal cause a change in the heat flux, which will be detected by the IR microscope.

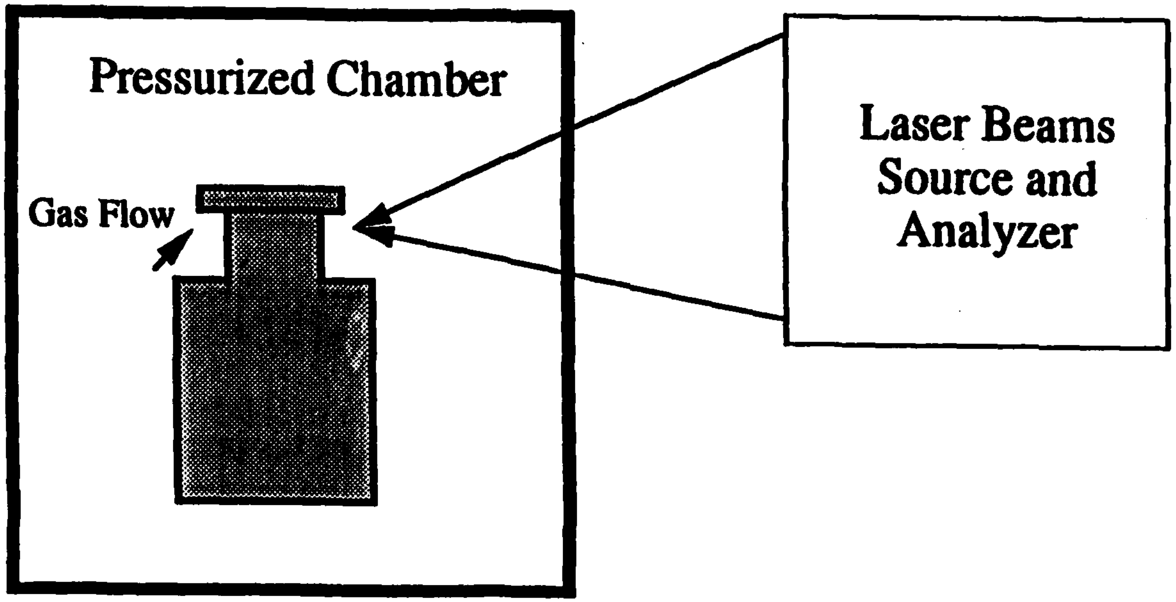
TapeTone Puffer



This on-line system can detect gross leaks but not very small leaks. It requires the package to have some headspace gas and a flexible lid. It consists of three stations:

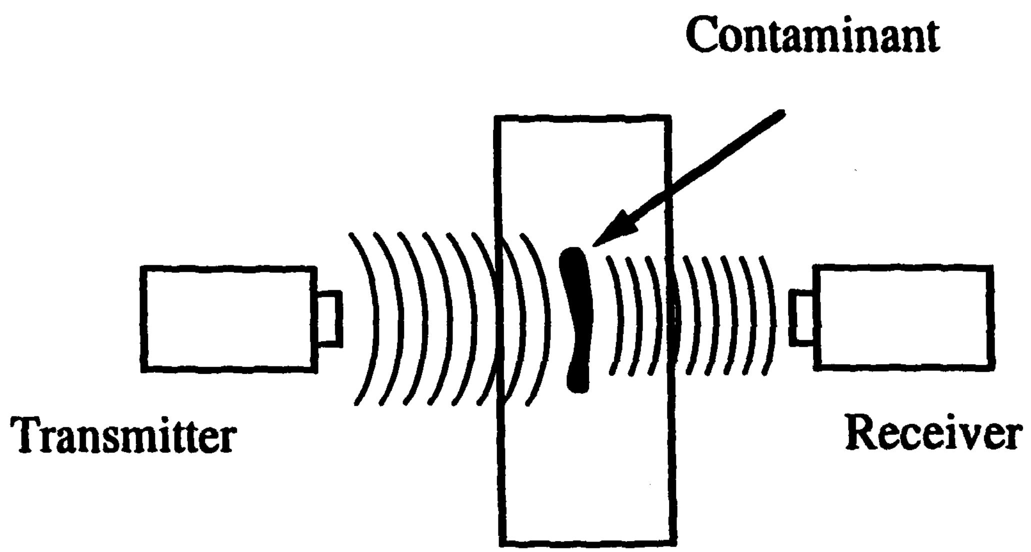
1. Heating station. The headspace is quickly expanded using radiated heat.
2. Lid deflection detection station: A sensor is used to detect lid puffing. For a leaky package, the lid will not puff, and for a good or slowly leaking package, the lid will puff.
3. Lid depression station: The lid is depressed with a platen. The load cell, which is connected to the platen, is used to determine if the package is a good or slowly leaking package.

Using Laser to Sensor Minute Gas Flow



This is an innovative technique for detecting leaks in rigid packages. Above is an example to illustrate the technique using a glass vial. The assumption is that leaks occur only around the closure cap. The technique consists of two steps: (1) the outside of the vial is pressured with nitrogen containing very fine inert particles; (2) two laser beams are focused at a point near the cap. If there is a leak, the pressure driving force will the gas to flow into the vial, and the gas flow will be detected by the laser beams. Either the vial or the laser beams can be rotated 360° so that the entire area around the cap can be inspected.

Ultrasonic Techniques for Detecting Food Contamination in Seal



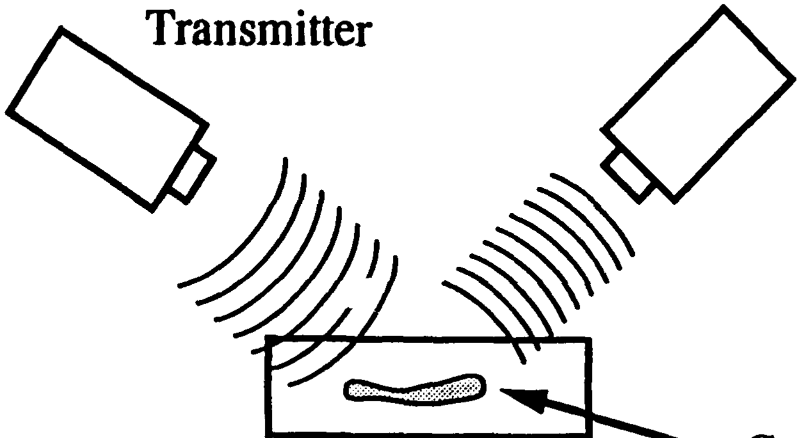
Operation: The seal of a package is placed between two ultrasonic transducers, a transmitter and a receiver. Ultrasound is transmitted and received during testing. The velocity and attenuation of ultrasound may be used as an indicator of whether the seal contains food contaminant, voids, wrinkles, etc.

Advantage: It is a nondestructive technique.

Disadvantages: Although preliminary laboratory studies have indicated that this technique can detect food contaminant, voids, and wrinkles in package seals, the technique is still in development stage, and more work is needed to investigate its commercial viability.

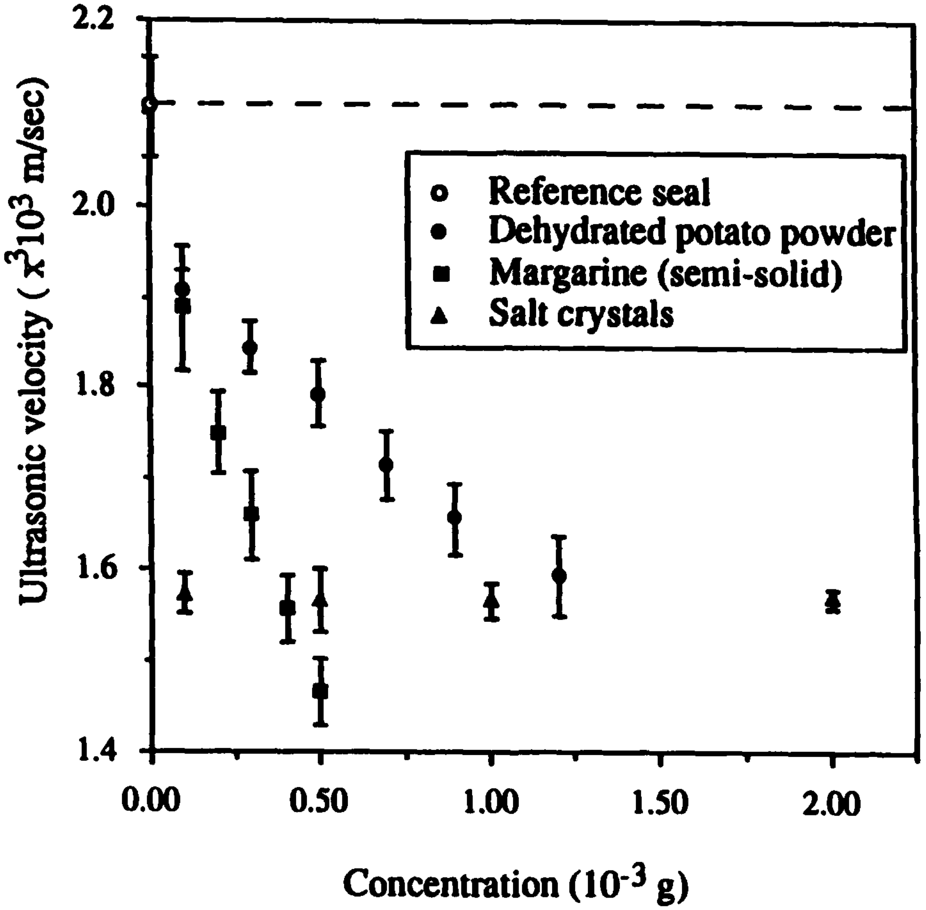
Contaminated seals are not necessary leaky or weak seal. They are only a indicate of potential problem.

Pulse Echo Ultrasonic Technique for Inspecting Seal Contamination



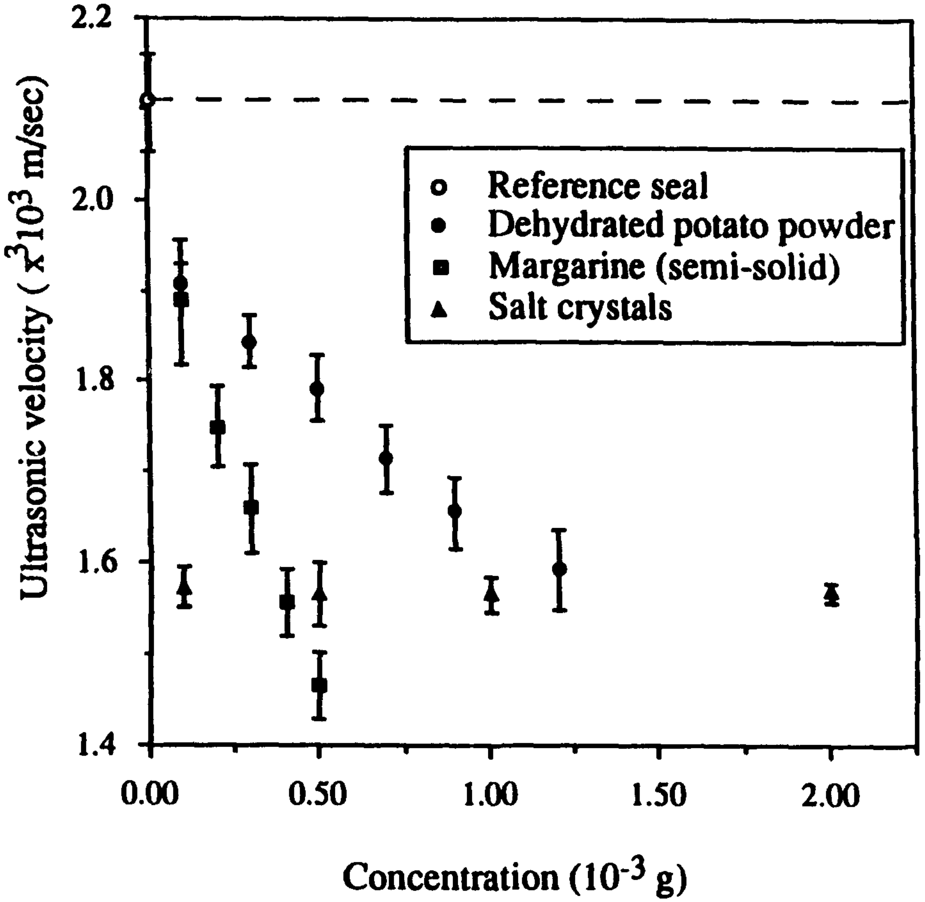
This is an alternative method of detecting seal contamination using ultrasonic technique.

Ultrasonic Velocity versus Contaminant levels



Ultrasound is found to be able to detect contaminants in package seals. The ultrasonic velocity is a good parameter of indicating the presence and the amount of contaminant. The more the contaminant, the lower the ultrasonic velocity.

Ultrasonic Velocity versus Contaminant levels



Ultrasound is found to be able to detect contaminants in package seals. The ultrasonic velocity is a good parameter of indicating the presence and the amount of contaminant. The more the contaminant, the lower the ultrasonic velocity.

Pressure Differential Technique

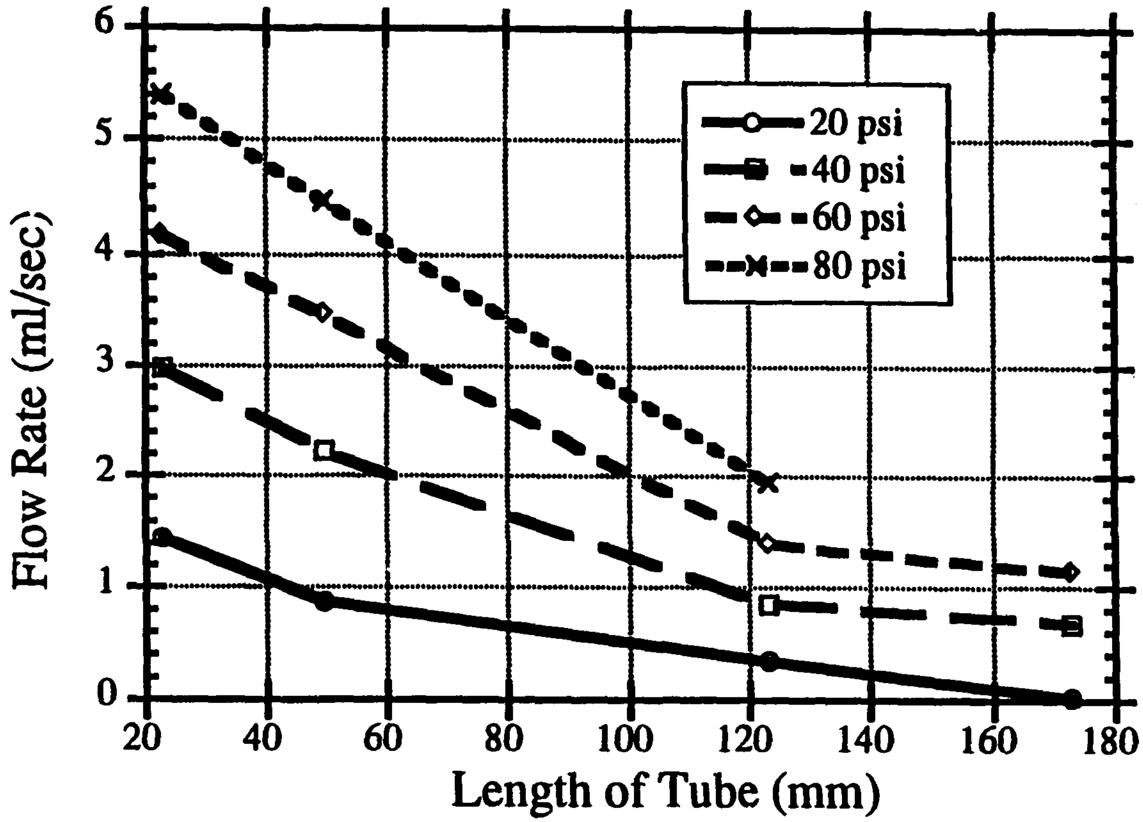
The higher the gas flow rate, the faster the response time.

$$\text{Flow} = \frac{\text{Driving Force}}{\text{Resistance}}$$

$$\text{Pressure Driving Force} = \Delta P$$

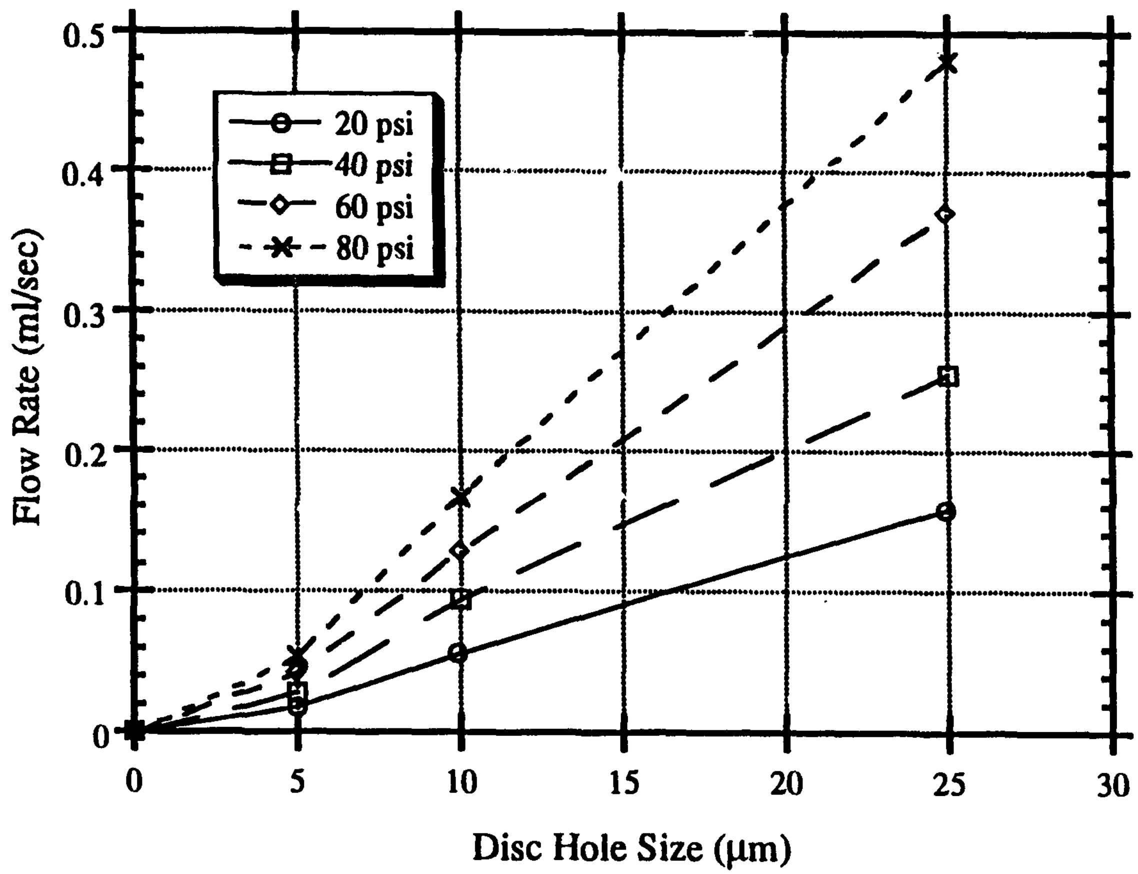
The resistance in a channel leak depends on the wall resistance, and it increases with decreasing channel leak diameter and increasing channel leak length.

Flow Rate vs. Tube Length (100 μm diameter)



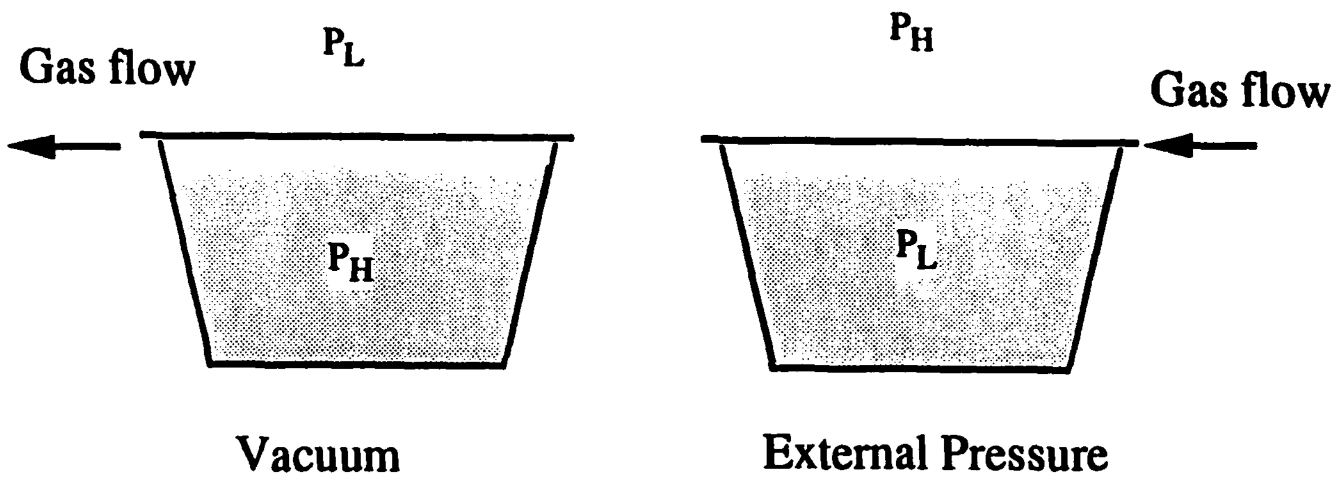
Several pressure differentials were applied across the ends of four capillary tubes. The capillary tubes are of various lengths and have the diameter of about 100 μm. The result show that the gas flow rate across the tubes increases with pressure and decrease with the tube length.

Flow Rate versus Disc Hole Size



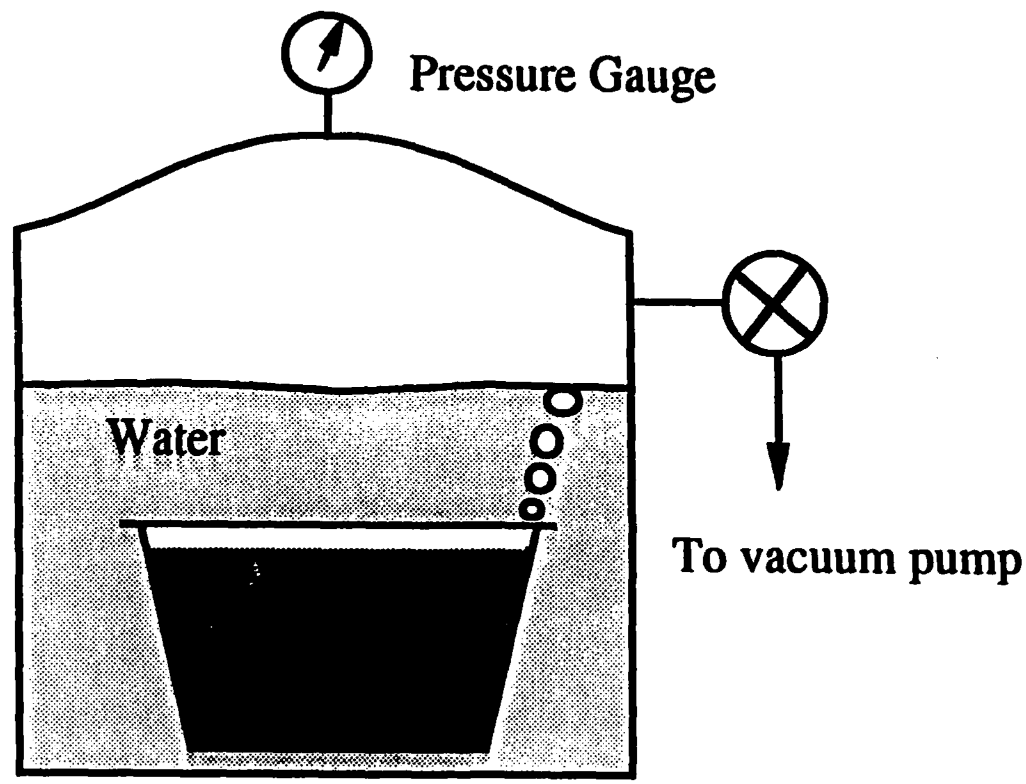
Very small holes were drilled on metal discs using laser technology. Pressurized nitrogen was applied across the discs, and the flow rates through the holes were measured. The data show that the flow rates increase greatly with increasing pressure difference and disc hole size.

Vacuum versus External Pressure Techniques



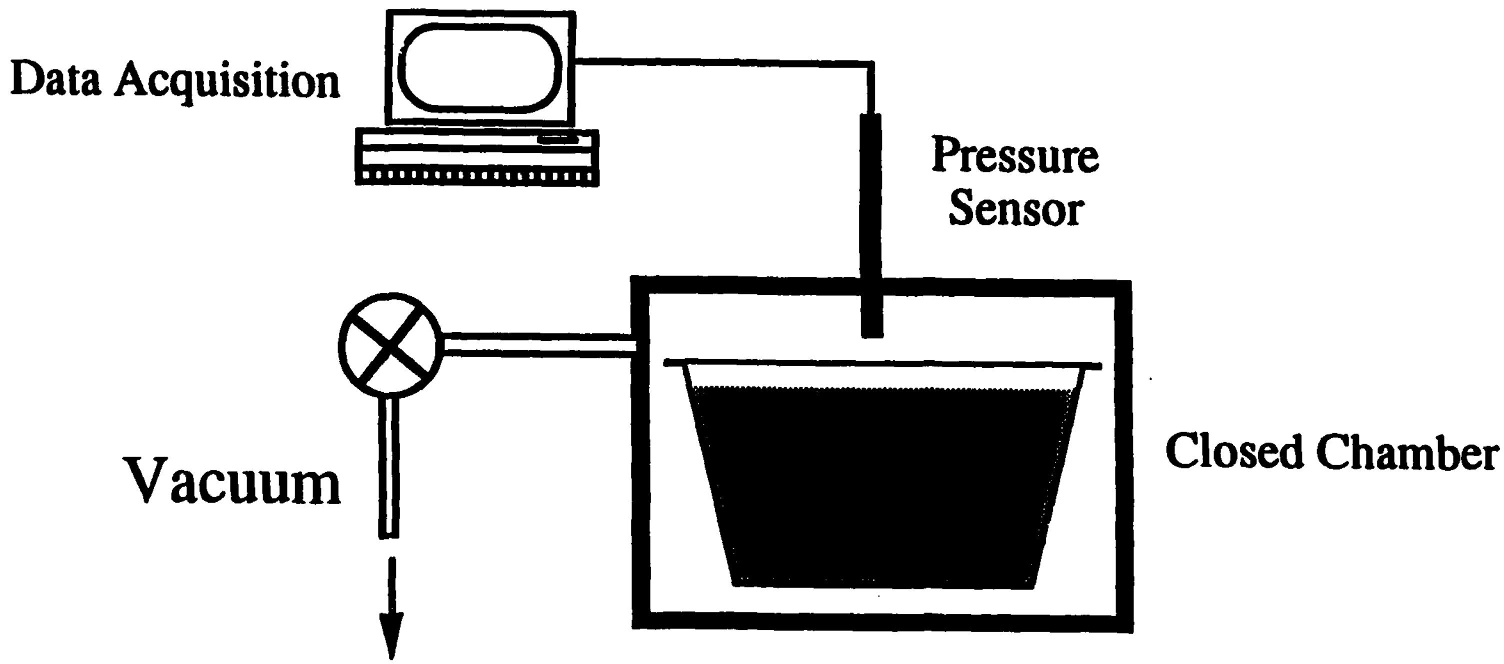
The direction of gas flow depends on whether vacuum or external pressure technique is used. For vacuum technique, the pressure inside the package is higher, and the gas is flowing out of the package. For external pressure technique, the pressure inside the package is lower, and the gas is flowing into the package.

Bubble Test



Operation:	The package is immersed in water inside a vacuum chamber. Any gross leak in the package is indicated by bubbles escaping from the package. It is possible to increase the sensitivity of this technique with the use of other fluid (liquid or gas) to replace water.
Advantages:	The technique is nondestructive, easy and inexpensive to perform. The location of the leaks can be found easily.
Disadvantages:	Only gross leaks can be detected. The technique is time consuming and labor intensive.

VACUUM METHOD FOR DETECTING LEAKS IN PLASTIC CONTAINERS



Operation: Vacuum is drawn from a closed chamber containing a plastic container. The valve connecting the chamber and the pressure controller is then closed. If there is a leak or leaks in the container, air will escape from the container causing the pressure in the chamber to increase with time. The pressure change, used here as a indicator for leaks, is monitored with a very sensitive pressure sensor and a data acquisition system.

Advantages: The technique is may be used for nondestructive on-line detection around the closure of rigid containers and bottles. Commercial units are available.

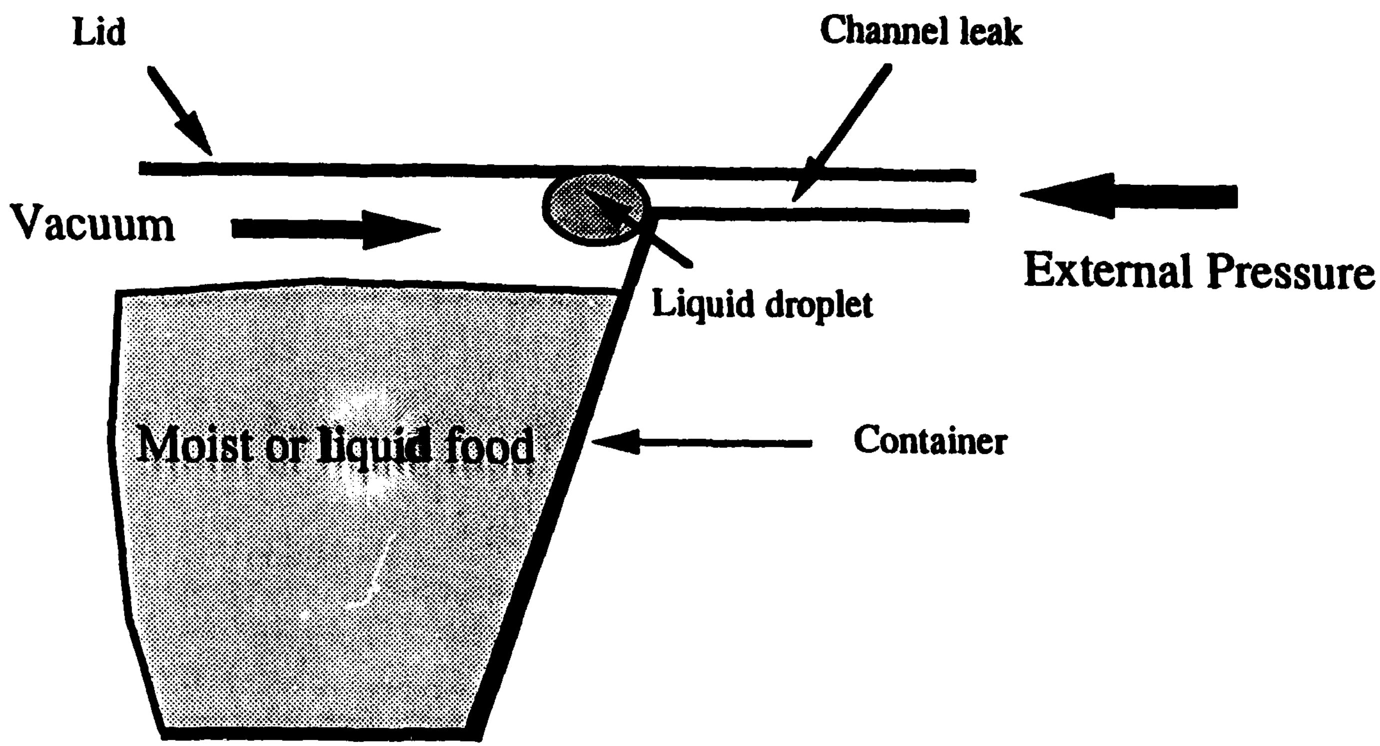
Disadvantages: The container must have residual gas.

The pressure difference between the inside and the outside of the container is less than one atmosphere. If the package contains wet food, it is possible that small holes are plugged by moisture condensate, making it difficult for the residual gas to penetrate these plugged holes with such a small pressure difference.

Limitations of Vacuum Techniques

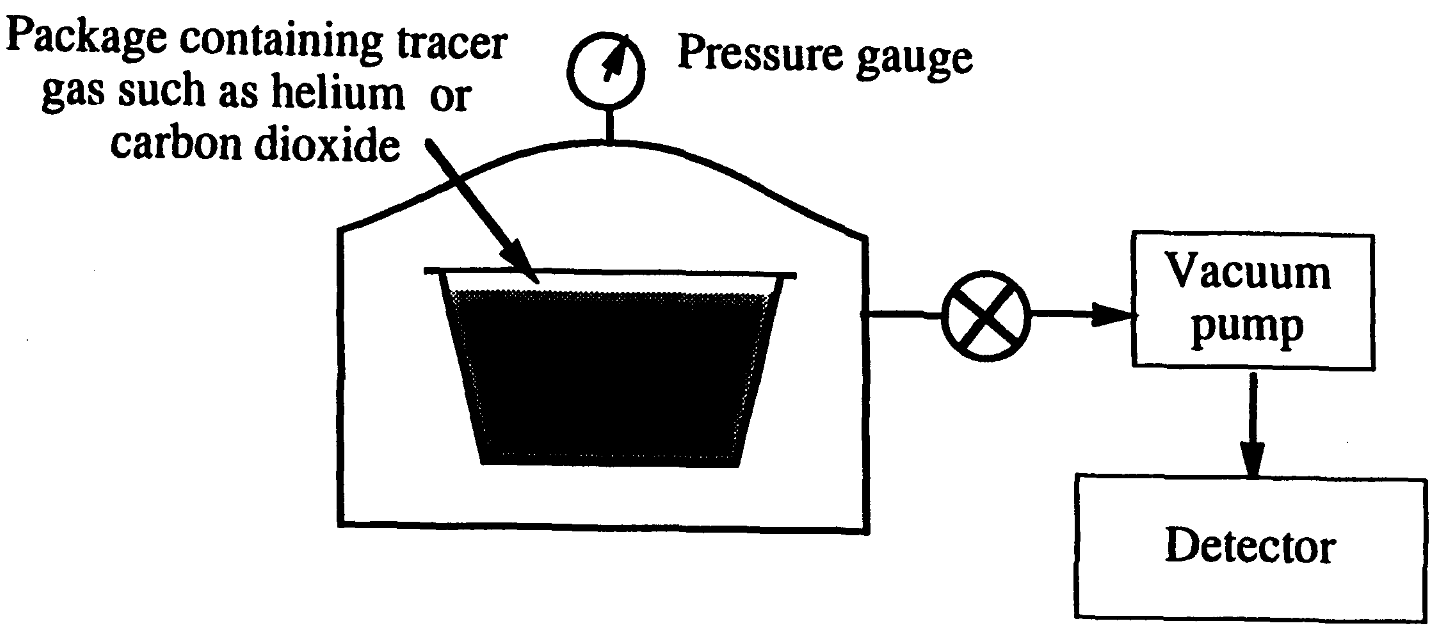
- Pressure difference limited to 1 atmosphere.
- Requires residual gas to move easily inside the package.
- Can't penetrate plugged holes and can't find very small leaks.
- Slow response time.

Leak Plugged by Liquid Droplet



The above diagram shows a liquid droplet plugging a channle leak. It is much easier to remove the droplet using external pressure than vacuum because the pressure difference driving force can be larger and the droplet does not have to pass through the micro-channel, which has high resistance to flow.

Tracer Gas Method



Operation: The closed chamber is vacuumed. If there is a leak or leaks in the container, tracer gas will escape from the container. A detector such as a mass spectrometer is used to detect the presence of tracer gas.

Advantage: It is a nondestructive and highly sensitivity technique.

Disadvantages: Tracer gas must be introduced into the package before sealing..

The response time any be slow, and the technique requires an expensive detector.

For some packages, such as those containing gravy, it may be difficult for the tracer gas to escape. This makes the technique useless.

Retorting may also make the technique useless. If the tracer gas leaks out the package during retorting, it will be no longer available for detection purpose.

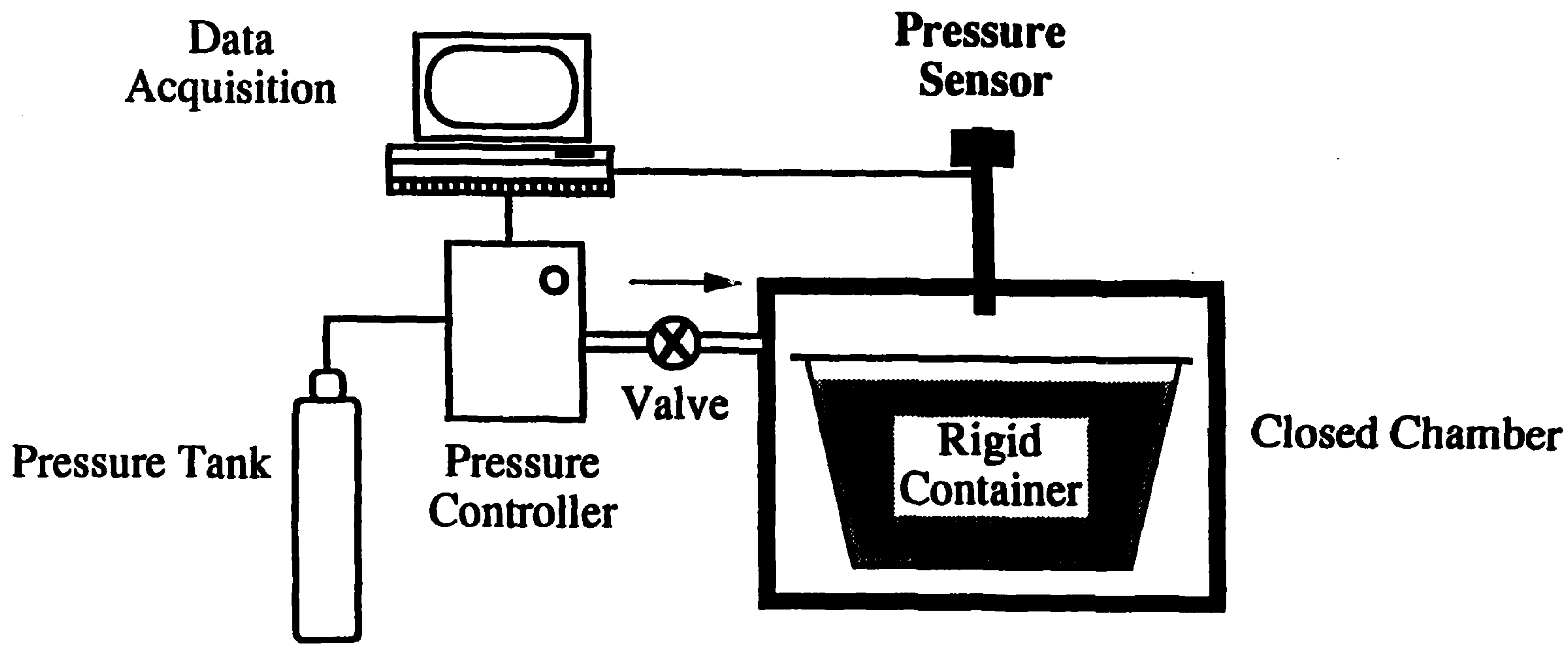
Tracer Gas Technique

- Advantages
    - Highly sensitive and able to detect very small holes
- Disadvantages
    - Requires tracer gases such as helium
    - Expensive and slow
    - Tracer gases may escape before testing rendering the technique not reliable

External Pressure Method

- Pressure difference may be much higher to 1 atmosphere.
- Does not required residue gas.
- Can penetrate plugged holes.
- Fast response time.

DETECTING LEAKS IN RIGID CONTAINERS USING A PRESSURE DECAY TECHNIQUE

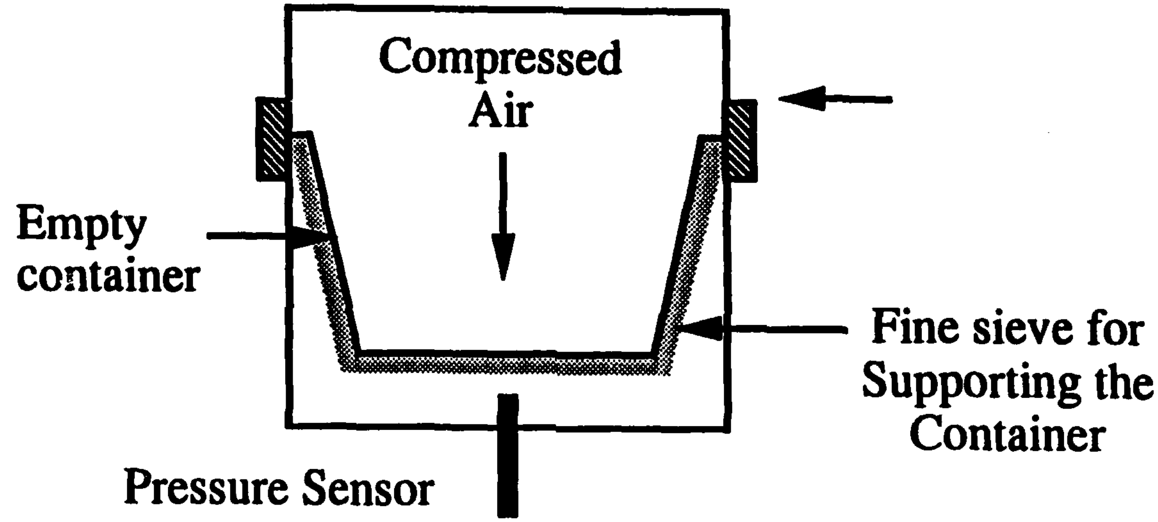


Operation: A closed chamber containing a container is pressurized with air to a pressure of 60 to 120 psi. The valve connecting the chamber and the pressure controller is then closed. If there is a leak or leaks in the container, air will go into the container causing the pressure in the chamber to drop with time. The pressure decay, used here as a indicator for leaks, is monitored with a very sensitive pressure sensor and a data acquisition system.

Advantages: The technique is may be used for nondestructive on-line detection around the closure of rigid containers and bottles. Commercial units are available.

Disadvantages: The technique does not work well with flexible containers.

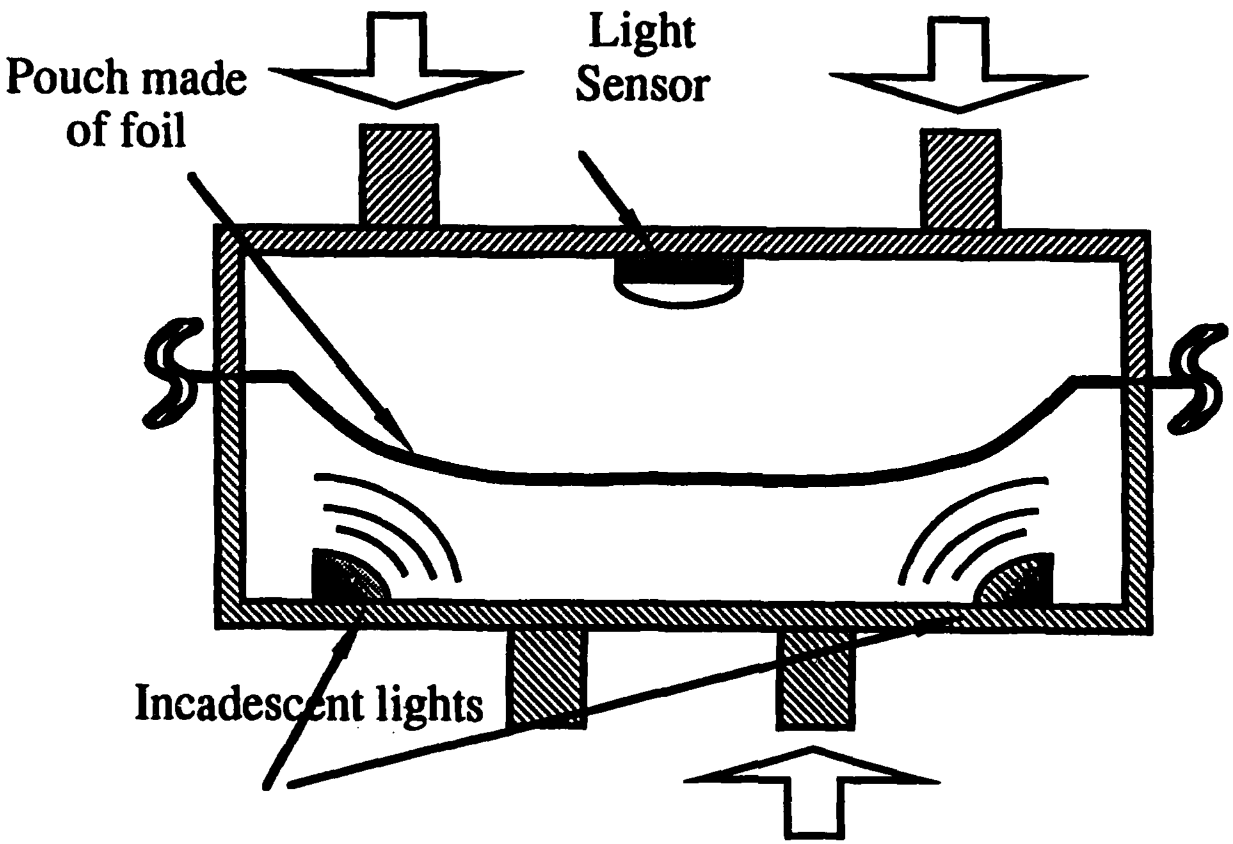
ISOLATION APPROACH
Step 1: Testing Empty Container With Compressed Air



The integrity of a package may be tested using an isolation approach consisting of two steps. The first step involves testing the empty package and the lid stock.

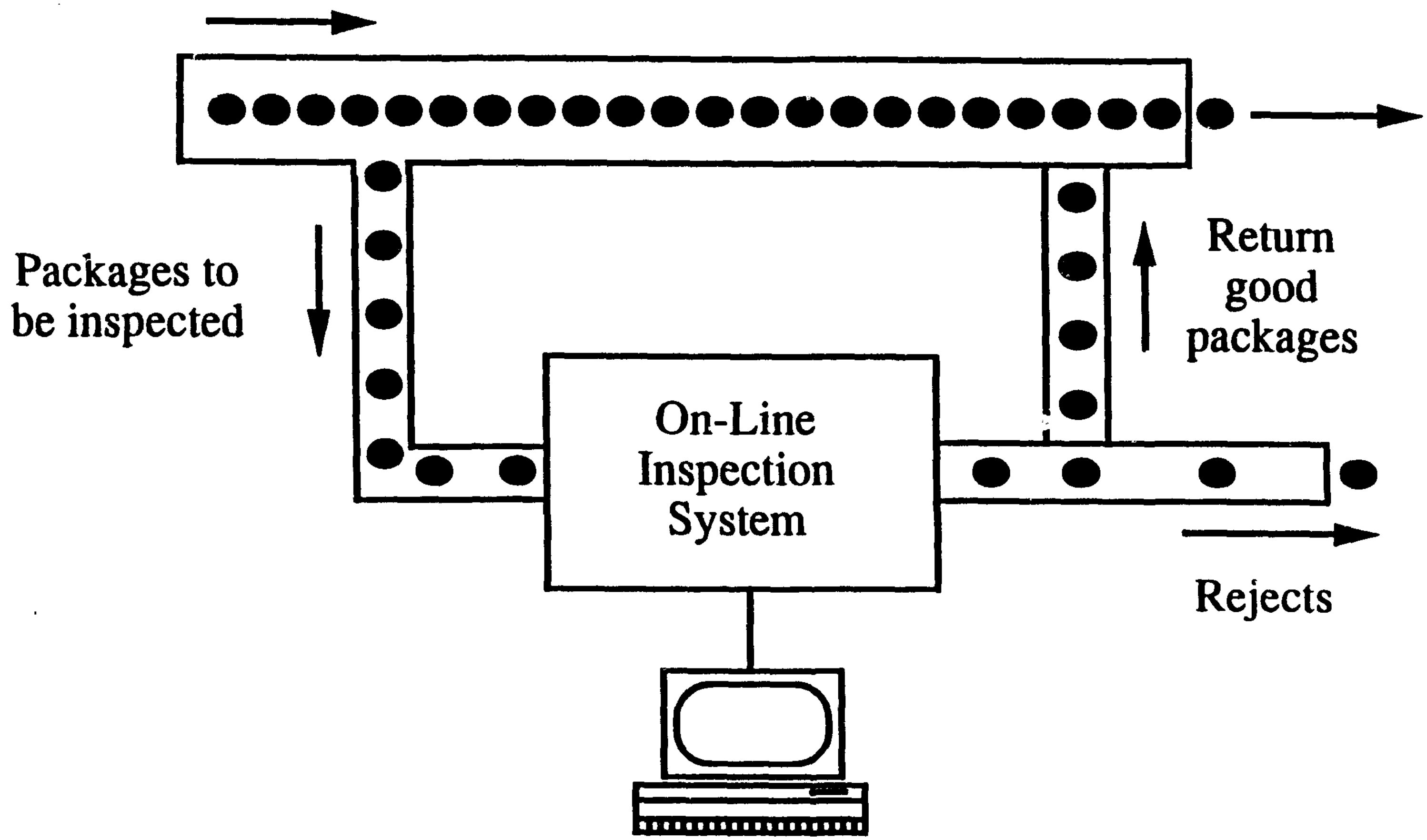
Shown here is an example of testing an empty container with compressed air. The air will flow through any leak in the container. As a result, a pressure increase will be detected by the pressure sensor on the other side of the package. The same technique can be used to test lid stocks for pinholes or cracks.

Isolation Approach
Step 1: Testing Empty Package with Light

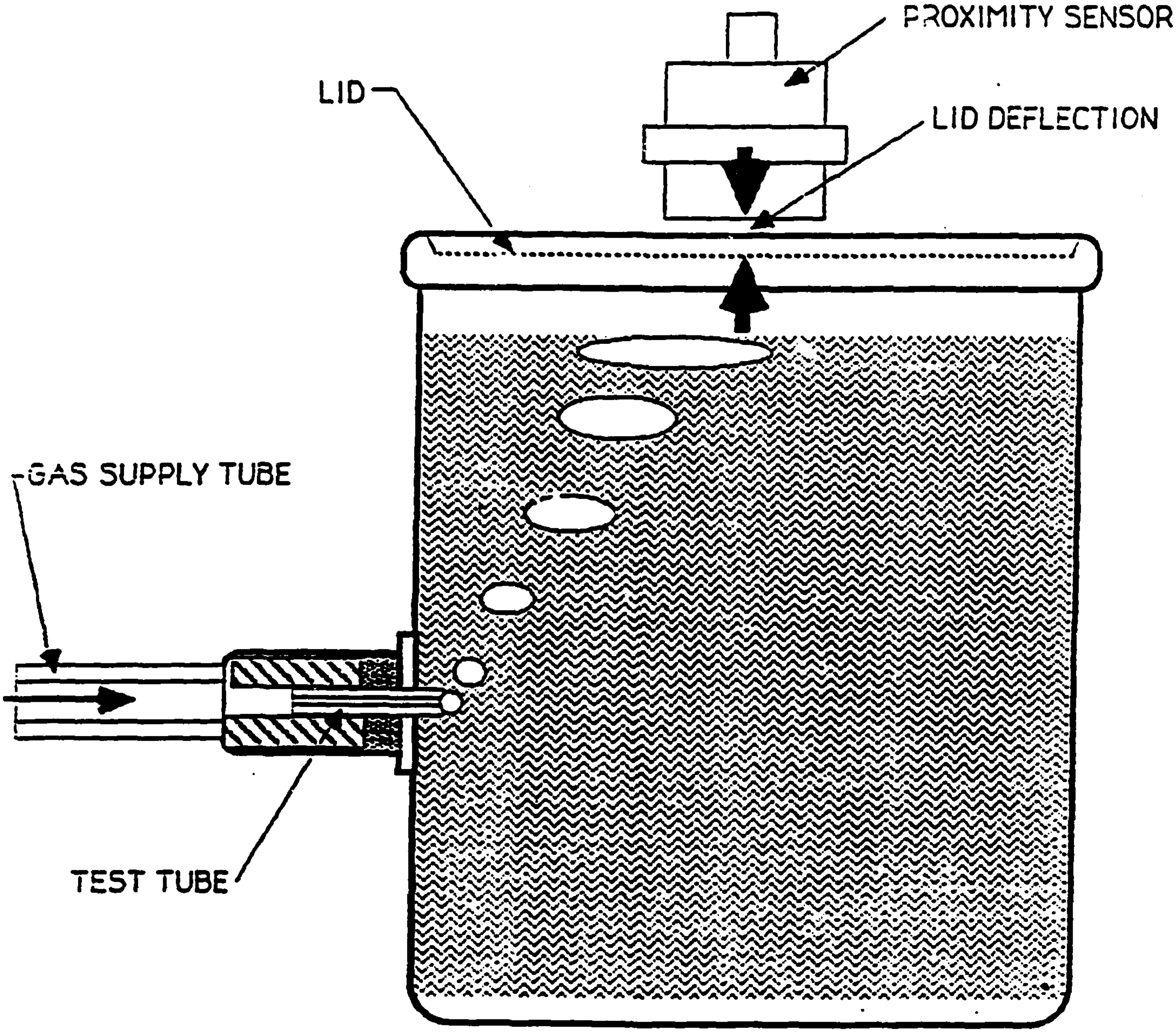


This technique may be used to detect pinholes in empty packages made of foil material, such as the pouch shown above. Light can easily pass through pinholes as small as 10 µm. An inexpensive sensor can detect light penetration within a fraction of second.

ON-LINE STATISTICAL INSPECTION PLAN



Statistical inspection is an alternative to 100% inspection when the throughput of the production line is higher than the thoroughput of the inspection system. Only a statistical samples of packages are inspected. The on-line feature provides immediate feedback for process control.

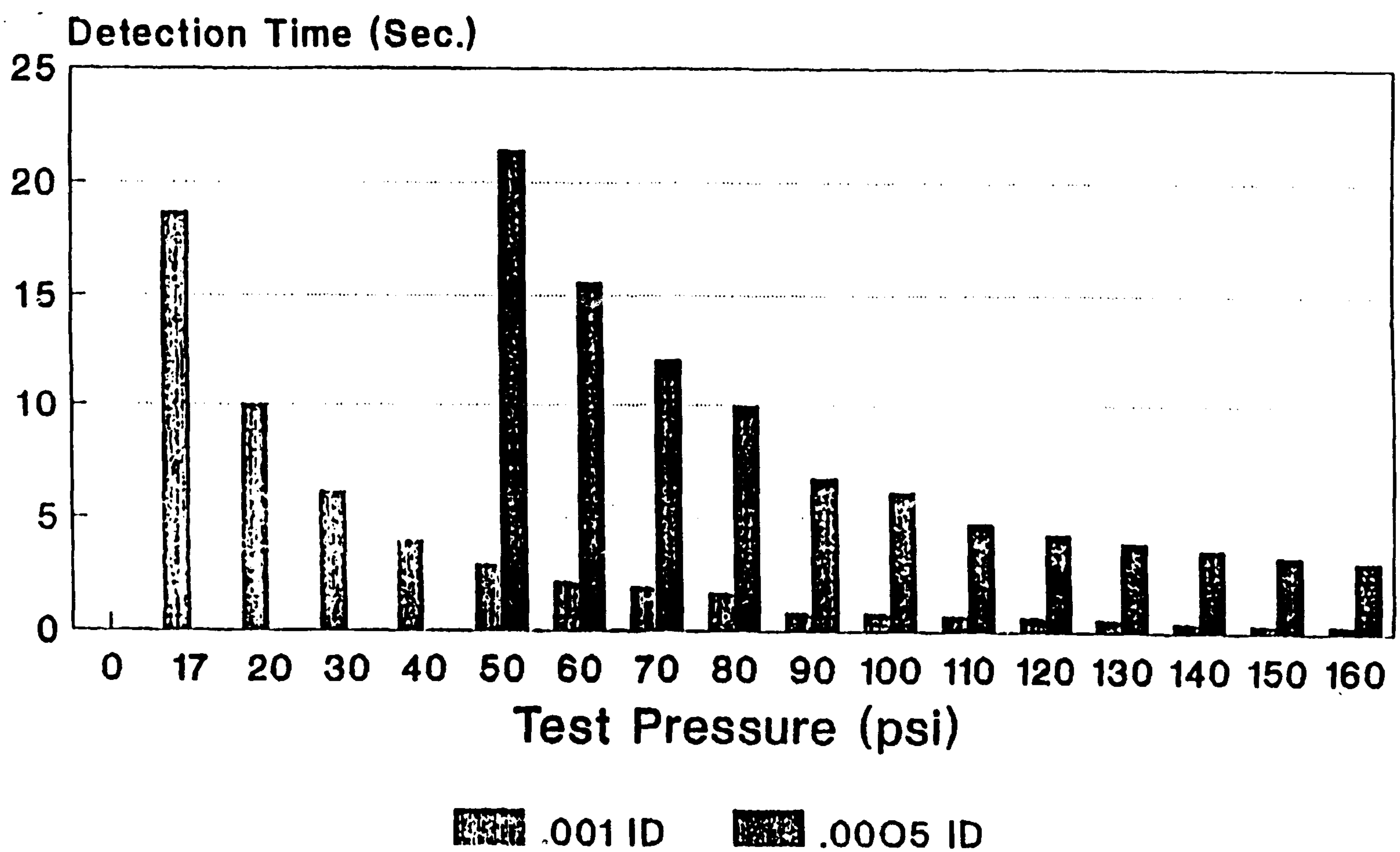


OMNI CONTAINER

TEST SET-UP

Deflection Time

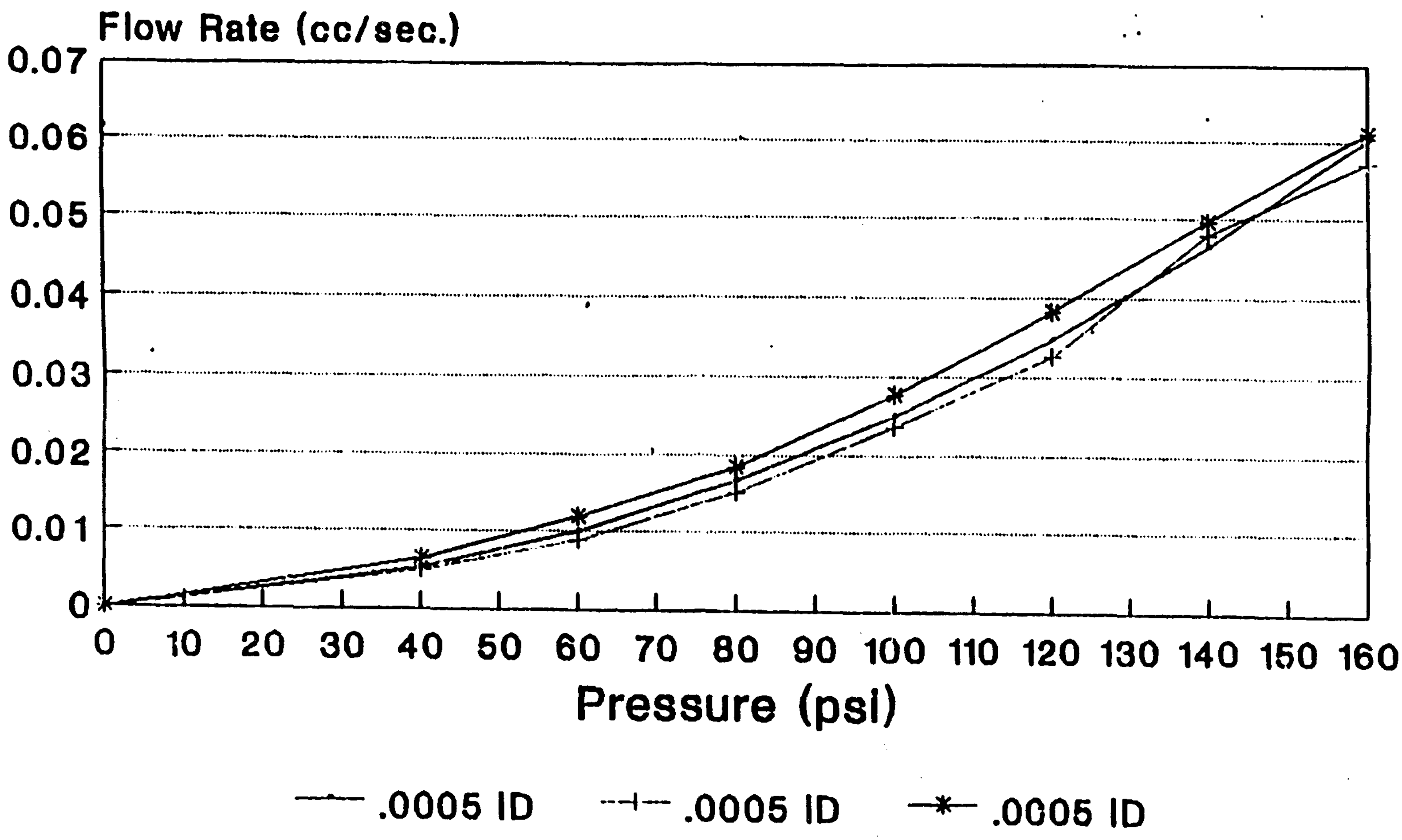
Time Requird to Deflect Lid .002"



Hole sizes .001 Dia. & .0005 Dia.

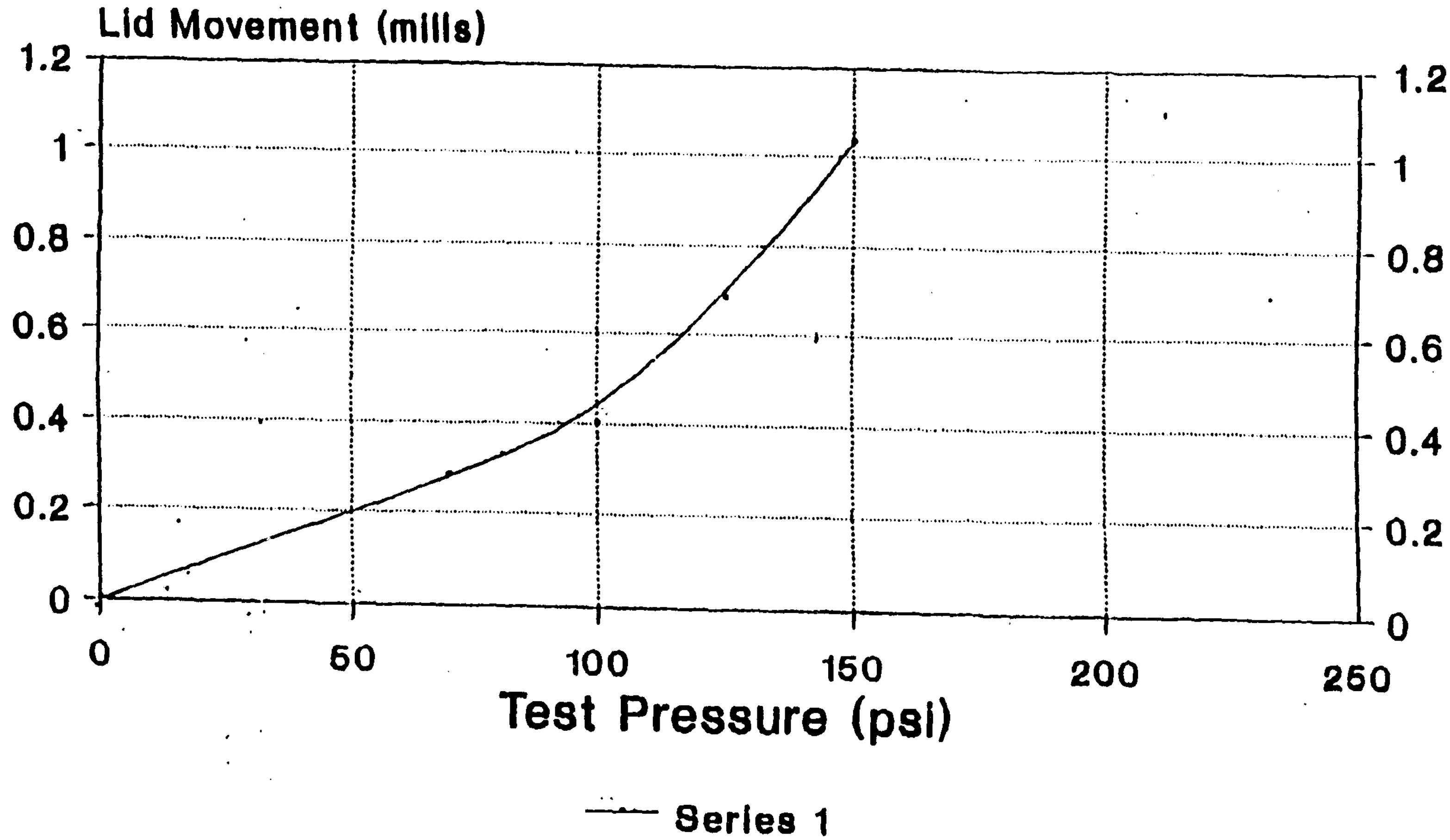
Flow Rate No.6 Tube

.0005 ID x .1765 Long



Back pressure .4087#/In2

Lid Deflection vs Test Pressure
2 Sec. Test Time - .0005 Dia Hole



Flow throw tube No.6 for 2 Sec.

Appendix 4.3

Materials presented at the management meeting on June 10, 1992

Objective

To define the feasibility of developing an on-line, non-destructive, high speed, and cost effective leak detection system for MRE pouches.

Phase I Specific Tasks

A. Establish system characteristics and requirements
B. Review current technology
C. Develop design concepts
D. Develop feasibility plan

Establish System Characteristics and Requirements

A. Pouch Characteristics (System Dynamics)

1. Location of leaks
2. Size of leaks
3. Factors related to leak detection such as residue gas, shape of the pouch, pouch material

B. Military Requirements (fusion test, burst test, dye penetrant test, etc.)

C. Leak Detection System Requirement

1. Accuracy
2. Speed
3. Sensitivity

Review Current Technology

A. Literature Review

   1. Military specifications, CRAMTD STP-3 Quality Control Manual, and USDA publications

   2. Reviewed journal articles

   3. Conducted computer search

B. Coordinated with Natick

C. Identified and contacted manufacturers of leak detection systems (companies such as Taptone, Wilco, Container Integrity Corporation, Mocon, etc.)

D. Consulted with CRAMTD coalition members such as NFPA, Reynolds Aluminum, and Natick

E. Consulted other experts such as Dr. Rauno Lampi, Professor John Floros of Purdue University, and researchers at School of Packaging at Michigan State University

F. Coordinated with CAFT In-Line Sensors Group

Techniques Investigated

A. Vacuum

B. High pressure

C. Tracer gases

D. Ultrasonic

E. Others (such as infrared thermography and caliper technique)

Selection of Design Concepts

A. Performance
   1. Accuracy
   2. Sensitivity
   3. Speed
B. Adaptability
C. Cost

Proposed Design Concepts

A. First 100% inspection

   1. First test the lid and the formed pouch with

      a) light

      b) pressure

   2. Then test the seal for

      a) channel leaks

      b) strength

B. Second 100% inspection

   1. Test the strength of the pouch

Advantages of Applying External Pressure

A. Provides more than 1 atmosphere pressure difference.

B. Can overcome the problem of water plugging of microholes.

C. Can detect small microholes in a short time.

D. Provides a test of the strength of the seal.

Feasibility Plan

A. Build experimental units according to the design concepts

B. Evaluate the performance of the experimental units

   1. using well characterized defective pouches (such as those of known leak size)

   2. by comparing it with the results obtained with the standard dye test, burst test, etc.

C. Further quantifying the system characteristics, such as

   1. the effect of retort on the integrity of the pouches (possible through coordination with the CRAMTD Qualification Project)

   2. the sensitivity of pouch movement as a function of gas flow, package geometry, residual gas, pressure difference, etc.

D. Refine the design for as needed.

Annual Saving in Testing Cost

A. Statistical Sampling

1. Assume 217,000 pouches being tested
2. Cost for dye penetrant test = $269,000 (from Peter Sherman)
3. Cost for burst test = $326,000 (assume testing 10 pouches per hour and cost of labor $15/hr)

B. In-line testing

1. Technician labor = $135,000
2. Maintenance and other cost = $20,000
3. Equipment depreciation = $200,000/10 = $20,000 (10 years life for equipment)
4. Total cost = $175,000

C. Potential Saving = $420,000

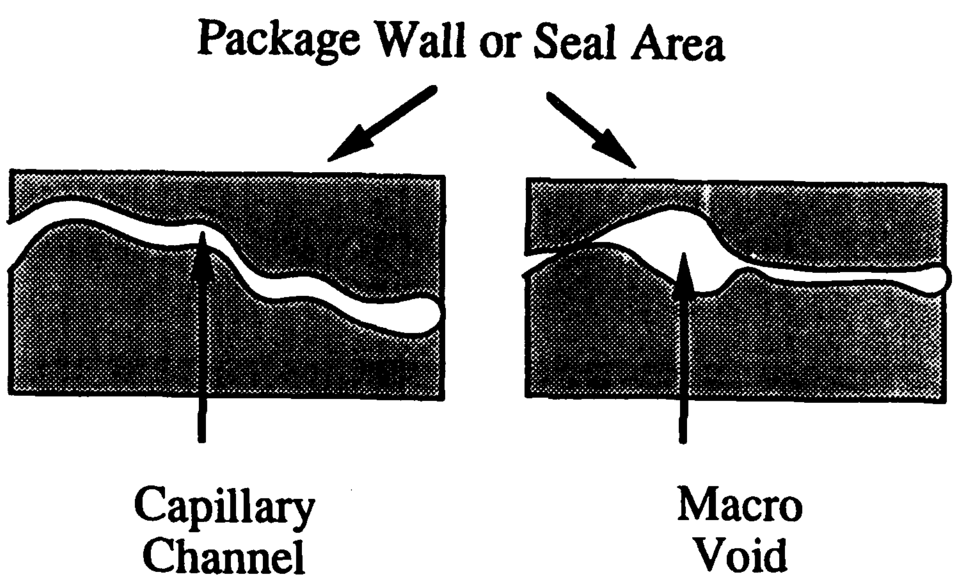
Other Savings

A. Provides immediate feedback for process control

B. 100% inspection

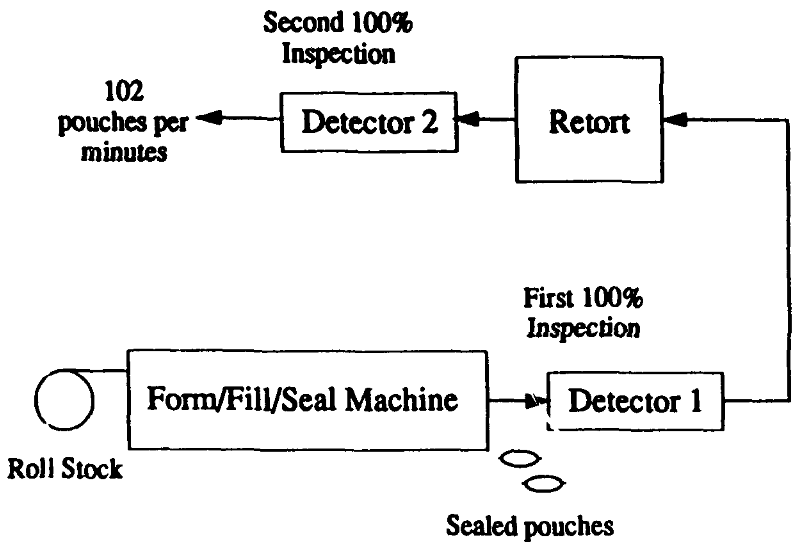
C. Nondestructive: saving in material cost

SOME PACKAGE DEFECTS

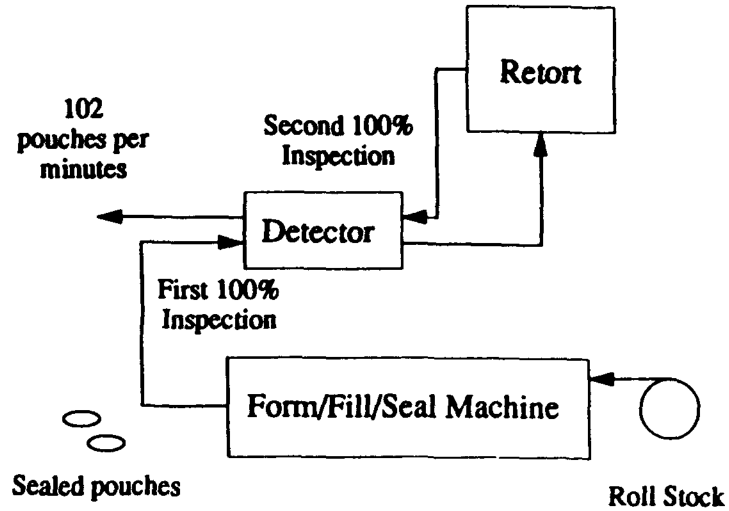


Here are some common defects which occur in the seal. These defects are due to poor sealing, contamination of the seal area, etc. Oxygen and moisture can penetrate through these defects into the package leading to quality loss of sensitive foods. A bigger concern is the penetration of microbes which may lead to health risk.

Should we use an one-unit or a two-units leak detection system?



Option 1. Two-Units Leak Detection System



Option 2. One-Unit Leak Detection System

K. Yam
1/4/91

Appendix 4.4

A paper entitled "Relationship between Seal Stress and Burst Pressure for Retortable Pouches' accepted by Jounral of Packaging Technology and Science for publication.

Relationship Between Seal Strength and Burst Pressure for Pouches

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ABSTRACT

Based on force analysis, the seal strength obtained from the peel test is equivalent to the product of the burst pressure and half of the plate separation obtained from the burst test. To verify this relationship peel tests and burst tests were performed using MRE pouches. Good agreement between the observed and predicted values was observed when the peeling times of the two tests were the same. This relationship is useful for comparing the performance of the two tests, as well as for establishing criteria for destructive and nondestructive testings.

Key Words: seal strength, burst pressure, peel test, internal burst test

Abbreviated Title: Relationship between seal strength and burst pressure

INTRODUCTION

Assuring seal integrity is a critical step in quality assurance programs for retortable pouches. Two common causes of seal defects are weak seals and channel leaks: the former may lead to package failure, and the latter may allow the entrance of microorganisms into the packages.

Peel test and burst test are commonly used to evaluate the seal integrity for retortable pouches.[1,2] The peel test is a form of tensile test that measures the maximum force, or seal strength, required to tear apart the seal of an 1-in. wide sample.[3] The test is simple to perform and can provide rather reproducible results; however, if many samples from each pouch are to be examined, the test can be time consuming. In the burst test, a pouch is first restrained between two parallel metal plates and then pressurized by gas injection through a hypodermic needle inserted into the pouch. The pressure required to burst the pouch, or burst pressure, is known to vary with the plate separation and the rate of pressurization. The internal burst test is considered to be a good overall measure of the ability of a pouch to withstand transportation and handling.[1]

The objective of this work was to define and verify a relationship between the seal strength and the burst pressure. Understanding this relationship is useful for comparing the performance of the two tests, as well as for establishing criteria for destructive and nondestructive testings.

THEORY

Fig. 1 shows a pouch restrained by two parallel plates separater' 'ith a distance 2R. When the pouch is inflated with air, the force acting on the upper body and bottom of the pouch is balanced by the reaction force exerted by the plates, while the force acting on the edges of the pouch is balanced by the reaction forces exerted by the wall of the pouch around the seal area. Because the pouch is flexible, the air pressure exerts a tensile force on the seal to peel it apart and causes the edges of the pouch to take on an approximately circular shape as illustrated in Fig. 1. Analyzing the y-component of forces around the seal area (Fig. 2), we obtain the equation

$$dF_y = P\,R \sin\theta\, d\theta \tag{1}$$

where F_y is force peeling one inch of the seal, P is internal pressure, R is half plate separation distance, and θ is angle shown in Fig. 2. Integrating Eq. (1) yields

$$F_y = \int_0^{\pi/2} P\,R \sin\theta\, d\theta = P\,R \tag{2}$$

At rupture, F_y and P can be substituted with the seal strength S (lb_f/in) and the burst pressure P_b(psi), respectively, yielding

$$S = P_b\,R \tag{3}$$

MATERIALS AND METHODS

To verify Equation (3), experiments were performed using 4' x 6' perform MRE pouches with three sealed sides. The pouch material was constructed with a PET/aluminum/PP laminate.

For peel test, 1-inch wide samples were cut from the pouches according to the ASTM standard.[3] An Instron tensile testing machine equipped with a data acquisition system was used to measure the stress-strain behavior of the samples. The distance between the two clamps of the tensile testing machine was set to be πR, so that the area of the sample acted upon by the peel test is the same as the area acted upon by the burst test. Various levels of crosshead speeds ranging from 0.039 to 20 in/min were used. The seal strength from each sample was obtained from the maximum peak of the stress-strain curve, and the tensile peeling time t_p (the time required to reach the seal strength) was calculated from

$$t_p = 60\,\Delta L / v \tag{4}$$

where ΔL was elongation at seal strength (in), and v was crosshead speed (in/min).

For burst test, the open side of each empty pouch was first heat sealed at 250 °C and 60 psi for 1 sec. The pouch was then restrained in a fixture consisting of two adjustable parallel metal plates separated by a distance of 2R (Fig. 1). A needle was pierced into the pouch through a small opening at the center of the upper plate, and nitrogen was injected into the pouch through the needle. The burst peeling time t_b was defined as the elapsed time between initial pressurization and pouch bursting, which decreased with increasing gas flow rate. A valve was used to control the gas flow rate so that specific burst peeling times could be obtained. Several plate separations were used in the experiment. All the pouches tested were found to rupture at the seals, indicating the seals were the weakest part.

All the experiments were conducted at room temperature, and each datum reported here was the average of eight replicates.

RESULTS AND DISCUSSION

Fig. 3 shows that seal strength (S) increases linearly with the logarithm of crosshead speed (v). Since tensile peeling time (t_p) is inversely proportional to v as described in Eq. (4), S decreases as t_p increases (Fig. 4), and the smaller the t_p, the stronger is its influence on S. Similarly, burst pressure P_b is also a function of burst peeling time t_b, decreasing with increasing t_b (Fig. 5), and a logarithmic relationship between P_b and t_b was also found (not shown).

Table 1 presents the data of tensile peeling time, burst peeling time, predicted burst pressure using Eq. (3), and observed burst pressure, for a plate separation of 0.5 in. To test the validity of Eq. (3), the predicted burst pressure was plotted against the observed burst pressure in Fig. 6. Within experimental error, all the data were found to be near the 45° line, indicating that the predicted and observed burst pressures are in good agreement. Note that for each data point it was necessary to closely match the tensile peeling time with the bursting peeling time; otherwise, the predicted and observed burst pressures might significantly differ from each other.

Eq. (3) was further tested with various plate separations. Fig. 7 shows that the observed and predicted burst pressures are again in good agreement. Note that the pouches can withstand very high pressure without bursting when they are restrained with small plate separations. When the plate separation is small, the surface area that the pressure can act on is also small, and as a result, at constant pressure, the tensile force acting on the seal is smaller when the plate separation is decreased.

It is important to emphasize that the validity of Eq. (3) is based on the assumption that the peeling times for the peel test and the burst test are the same. Fig. 4 and 5 indicate clearly that small peeling times (say, below 20 sec.) affect the seal strength and burst pressure greatly. The tensile peeling time is a complicated function of gauge length,

crosshead speed, and stress-strain properties of the pouch material and the seal. Similarly, the burst peeling time is a complicated function of plate separation, rate of pressurization, and stress-strain properties of the pouch material and the seal. Thus it is necessary to consider the testing conditions when comparing results obtained from the peel test and the burst test.

Eq. (2) states that the tensile peeling force exerted on the seal (F_y) is equal to the product of the internal pressure (P) and the half plate separation distance (R). Therefore, it is possible to maintain F_y unchanged even if P is increased, by choosing a smaller R. This flexibility of varying R is particularly useful for designing nondestructive tests that use the technique of applying external pressure to the seals of packages.[4] The response times of these tests can be greatly reduced by applying high external pressure. However the high pressure may also cause the seals to rupture prematurely. The occurrence of these ruptures can be avoided by restraining the seal with a small plate separation, and Eq. (2) may serve as a design equation for this purpose.

ACKNOWLEDGMENT

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3. ASTM standard F88-85. Seal Strength of Flexible Barrier Materials.
4. T. Stauffer, *Journal of Packaging Technology*, 2, 147 (1988).

Table 1. Relationship between peeling time and burst pressure. The predicted burst pressures are calculated using Eq. (3). Each datum is the average of at least 8 replicates, and the value after the ± sign is the sample standard deviation.

Tensile Peeling Time t_p (sec)	Burst Peeling Time t_b (sec)	Predicted Burst Pressure (psi)	Observed Burst Pressure (psi)
148.5±24.4	146.6±13.6	56.8±1.3	56.3±1.8
74.6±5.9	73.9±7.8	60.2±1.9	62.8±2.1
38.8±5.2	36.9±5.5	63.2±2.0	64.1±2.4
21.3±2.9	22.1±2.9	67.2±1.9	69.0±2.1
10.8±0.9	10.4±1.0	71.6±2.0	72.9±2.6
6.0±0.6	5.8±0.3	73.9±1.2	75.6±3.1

Figure Captions

Fig. 1. A schematic of internal burst test for a flexible pouch.

Fig. 2. Analysis of force near the seal area.

Fig. 3. Effect of crosshead speed on seal strength (v_0 = 1 in/min).

Fig. 4. Effect of tensile peeling time on seal strength.

Fig. 5. Effect of burst peeling time on burst pressure (plate separation of 0.5 in).

Fig. 6. Predicted versus observed burst pressures (plate separation of 0.5 in).

Fig. 7. Comparison of predicted and observed burst pressures at various plate separations.

Figure 1

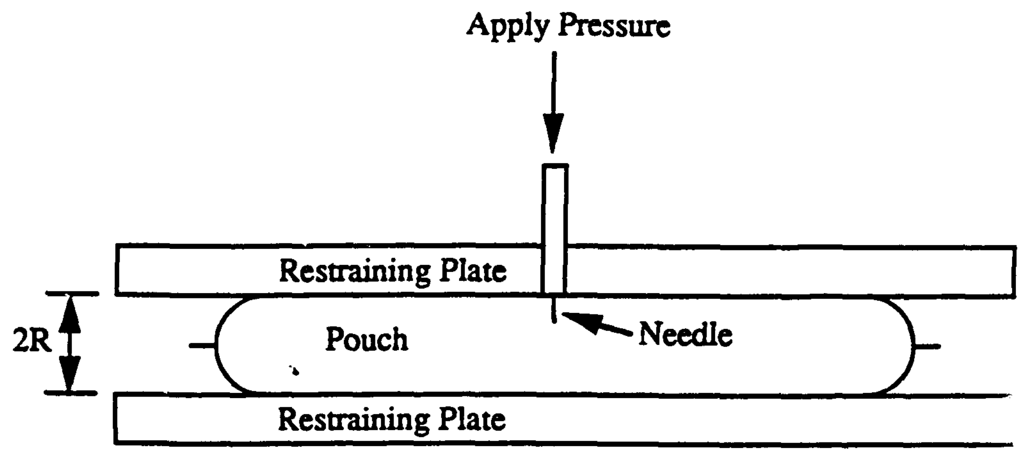

Apply Pressure
Restraining Plate
2R
Pouch
Needle
Restraining Plate

Figure 2

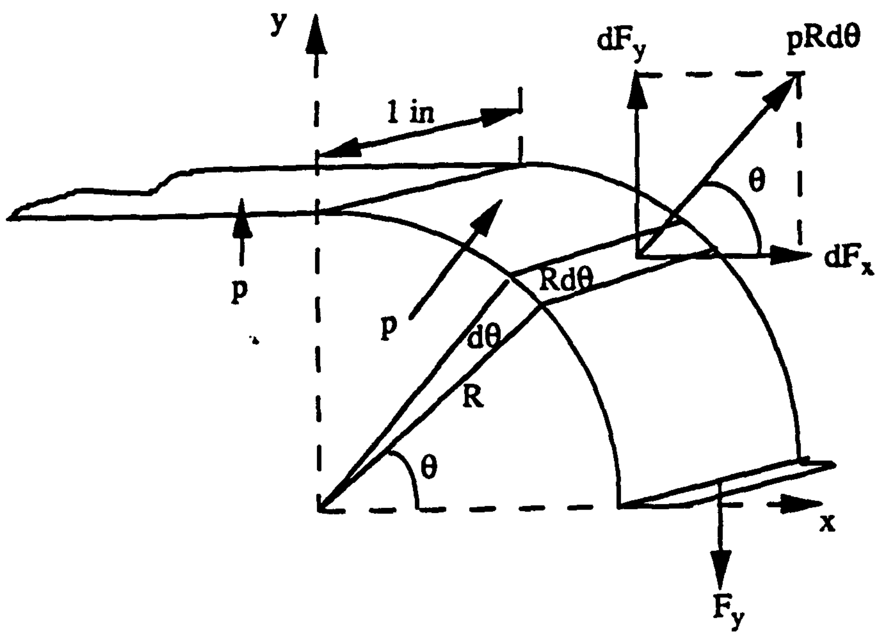


Figure 3

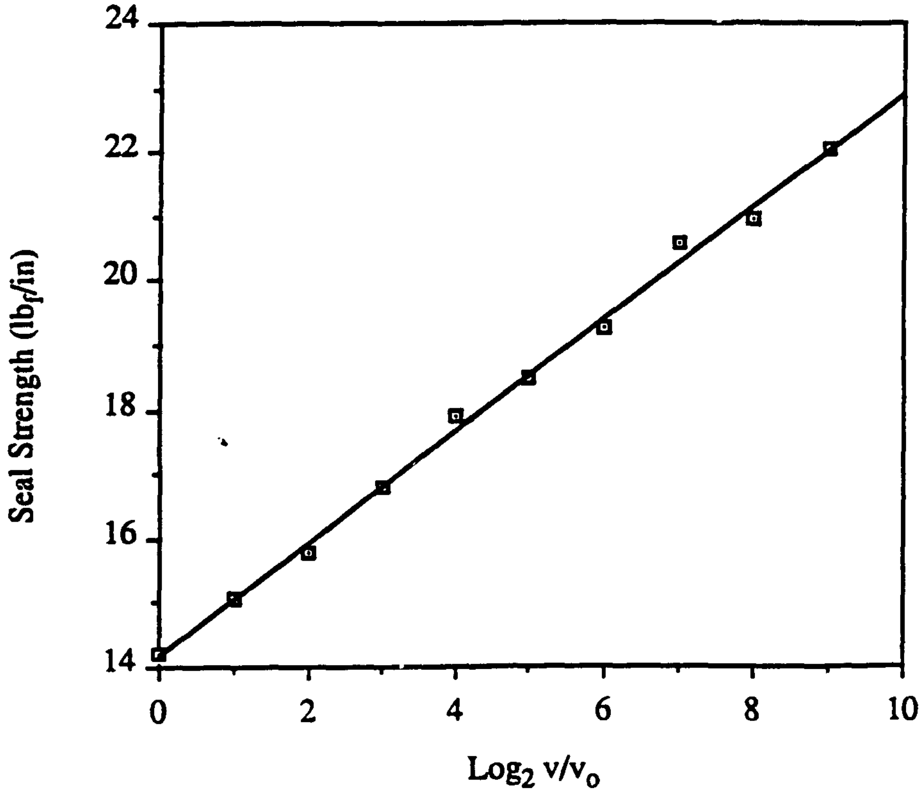
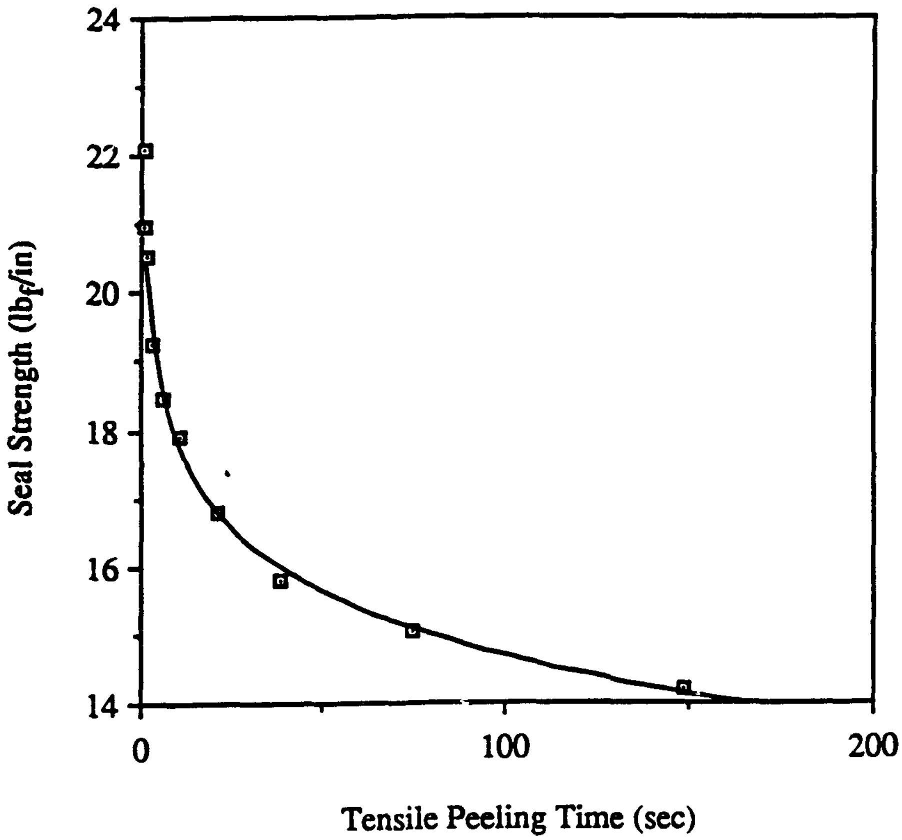
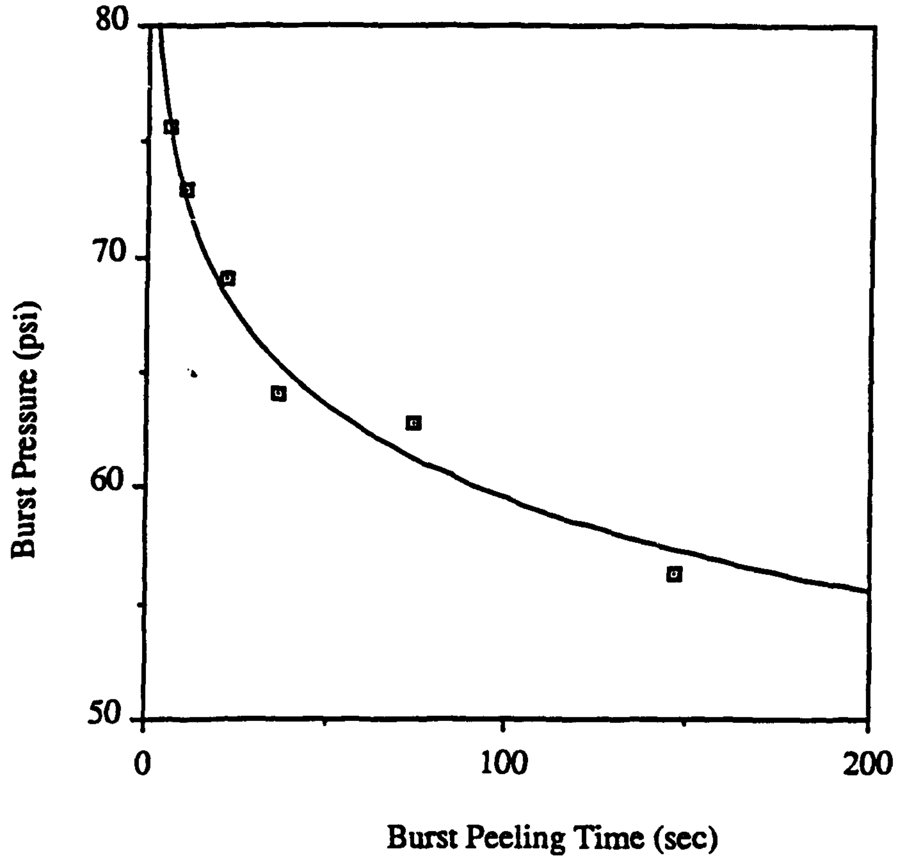


Figure 4



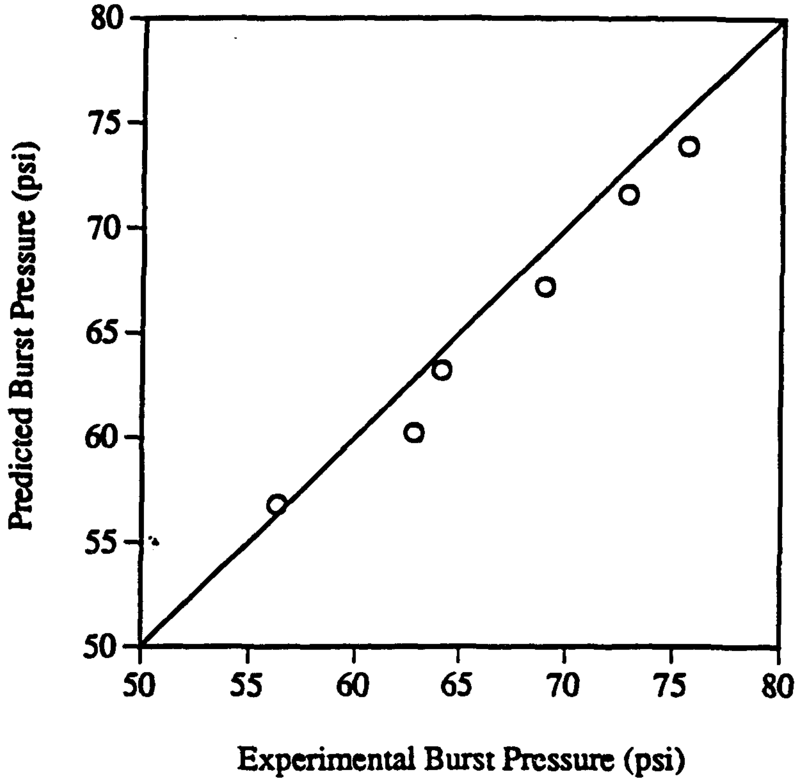
24
22
20
18
16
14
0
100
200
Seal Strength (lb_f/in)
Tensile Peeling Time (sec)

Figure 5



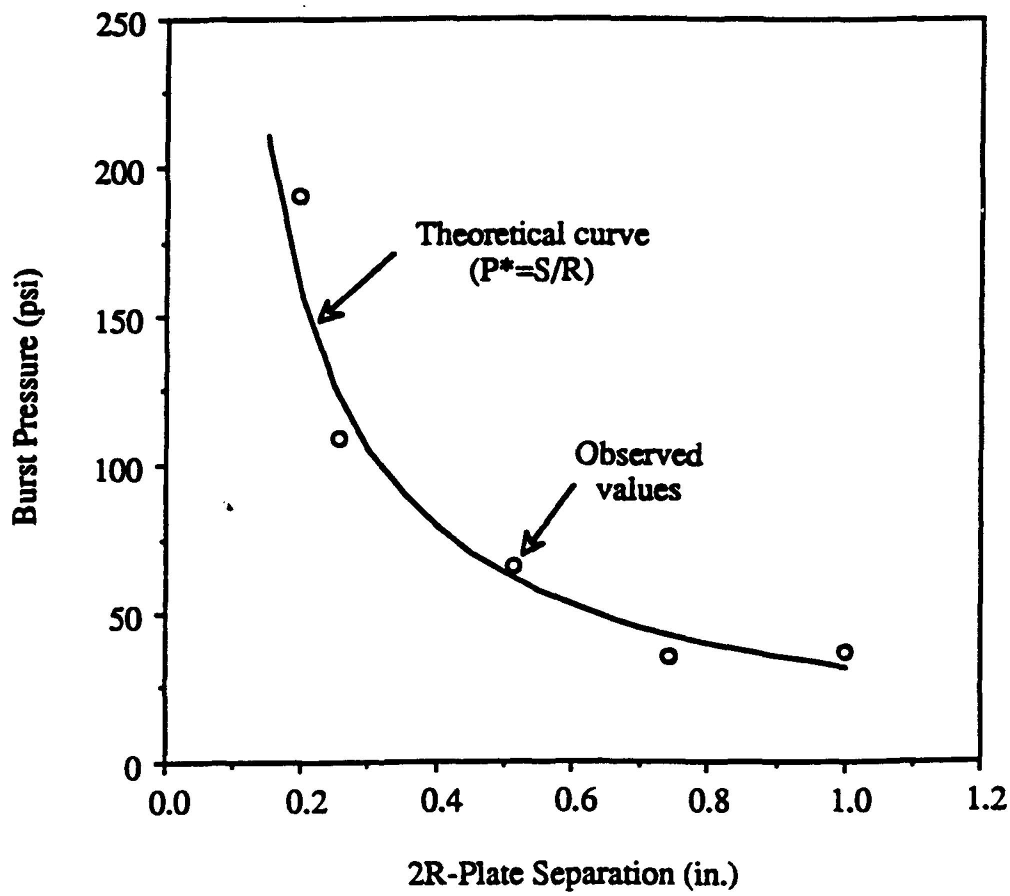
80
70
60
50
Burst Pressure (psi)
0
100
200
Burst Peeling Time (sec)

Figure 6



80
75
70
65
60
55
50
50
55
60
65
70
75
80
Predicted Burst Pressure (psi)
Experimental Burst Pressure (psi)

Figure 7



250
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Burst Pressure (psi)
2R-Plate Separation (in.)
Theoretical curve
(P*=S/R)
Observed
values